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A Survey of Recent U.S. Developments in International Agricultural Trade Models

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A SURVEY OF RECENT U.S. DEVELOPMENTS IN INTERNATIONAL AGRICULTURAL TRADE MODELS, by Robert L. Thompson. International Economics Division, Economic Research Service, U.S. Department of Agriculture. Bibliographies and Literature of Agriculture No. 21.

ABSTRACT

This report critically reviews econometrically estimated export demand equations, multiregion world trade models, including nonspatial and spatial price equilibrium models, and trade flow and market share models. Both single- and multiple-product models are treated. The report describes each modeling approach and its distinguishing characteristics, surveys the recent research, identifies technical and empirical problems, and evaluates its contribution to the objectives of agricultural trade modeling. The report ends with an appraisal of the state of the art and recommends directions for future research and modeling work on agricultural trade.

Keywords: International trade, modeling, econometrics, agricultural trade, systems analysis, trade policy, forecasting, mathematical programming, spatial equilibrium, exports.

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SUMMARY

A number of advances have been made in agricultural trade modeling in the last decade. Most of the research, however, has fallen short of its potential for contributing to understanding the world markets and the interrelationships among trading countries. The quality of the empirical parameter estimates in many studies surveyed was subject to question. Inadequate data (no single organization collects and banks all the data needed by trade researchers) and insufficient resources to collect better data lie at the root of many problems with existing trade models. Furthermore, specification errors and use of inappropriate estimators often biased the estimates of parameters in the models. The generally weak empirical content was the principal deficiency of all the trade models reviewed.

The simplest means of including international trade in existing U.S. commodity market models was to add export demand or import supply equations. This approach, however, has limited capabilities. Even with acceptable parameter estimates, such two-region models can be used to analyze only domestic policy issues because it is impossible to tell how to shift the export demand schedule in response to events in individual foreign countries.

Multiple-region models are basically simultaneous systems of equations specified to reflect the behavior of a number of trading regions and their interrelationships through the world market. The three classes of multiple-region models--spatial price equilibrium models, nonspatial price equilibrium models, and trade flow or market share models--differ principally in the nature of the price linkages assumed to hold among trading regions and in the mathematical procedure used to solve the models.

Nonspatial price equilibrium models generally include more domestic market detail and are often better validated than other multiple region models. Work on these models has improved our understanding of the interrelations among different countries' agricultural sectors. Nonspatial equilibrium models generate the net trade of each region, not trade flows and market shares. For some purposes this is a disadvantage. While tariff policies can be easily reflected in such models, most have an exaggerated free trade bias. Some very good work, nevertheless, has been done on estimating price transmission equations and policy reaction functions to reflect the policy environment in which trade occurs. Nontariff barriers to trade, which dominate in agricultural markets, have been much more difficult to reflect in nonspatial equilibrium models than tariff policies.

Spatial price equilibrium models are the most common agricultural trade models. This approach has three advantages: it generates trade flows and market shares, it is easy to introduce quotas and other nontariff barriers to trade, and it generates a spatial pattern of prices consistent with transportation costs. Most models have been linear and solved by quadratic programming. The disadvantage of linear equations has been overcome by separable programming, Bender's decomposition, and nonlinear solvers. Nevertheless, the spatial equilibrium technique mathematically cannot replicate all the observed trade flows for a variety of reasons: the product may not be perfectly homogeneous, but may be differentiated by country of origin; harvests occur 6 months out of phase in the Northern and Southern Hemispheres; some countries impose quota restrictions on trade flows; and importers may diversify their purchases among several suppliers to spread risk. Nevertheless, work with these models has contributed, in particular, to testing spatial equilibrium theory and to carrying out trade policy analyses.

While a number of different techniques have been employed in trade flow and market share models, all assume that importers differentiate goods by country of origin. Several mechanical techniques have been applied, ("transition matrices," constant market shares, and Markov models) which, although useful for forecasting, generally lack normative content and can offer little guidance for policy formulation. Attempts to estimate demand equations for exports by destination, market share equations, and elasticities of substitution for various agricultural commodities have generally supported the hypothesis that goods are differentiated by country of origin. A few attempts have been made to integrate this finding into complete agricultural trade models, but such models need better empirical content. This is an active current area of research.

The strongest recommendation for future trade modeling work is to improve the empirical content of existing models. This will require, among other things, improved data availability, particularly on prices and policies. Work is also needed on evaluating the relative importance of the hypothesized causes of the divergences of observed trade flows from what spatial equilibrium theory would lead one to expect and on incorporating imperfectly competitive behavior into agricultural trade models.

A Survey of Recent U.S. Developments in International Agricultural Trade Models

Robert L. Thompson*

INTRODUCTION

Events in the early seventies signaled an abrupt shift for U.S. and world agriculture. A decline in world grain production in 1972, coupled with dramatic increases in the demand for U.S. exports and the drawing down of stocks, led to increased concern about the ability of the world to feed itself and about the U.S. role. These events, together with a general increase in U.S. agricultural exports and a recognition of the role of the export market in domestic price formation, led to a burst of empirical research activity in the second half of the seventies on international agricultural trade.

The objective of this report is to survey the recent developments in modeling and forecasting world agricultural trade. The review emphasizes models that include the United States as one of the trading regions and open-economy models of U.S. agricultural commodity markets which explicitly include export demand or import supply. The report does not review the largely descriptive, nonquantitative or purely analytical literature on agricultural trade policy, comparative advantage, and international marketing institutions. Nor does it review purely theoretical contributions to the agricultural trade literature.

The survey begins by reviewing extensions of existing models of U.S. agricultural commodity markets to include world trade by simply adding an econometrically estimated export demand or import supply equation of the rest of the world. Following that section is a survey of multiregion world trade models, including nonspatial and spatial price equilibrium models, as well as market share and elasticity of substitution models. Both single-product and multiple-product simultaneous models are treated in each section. Each section provides some background on the modeling approach, describes its distinguishing characteristics, surveys the recent contributions in the area,

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identifies technical and empirical problems, and evaluates the extent to which that approach contributes to one or more of the above objectives of agricultural trade modeling. The report ends with an overall appraisal of the state of the art and suggests needed directions for future research and modeling work on agricultural trade. A comprehensive bibliography is included.

The U.S. economy has become increasingly interdependent with the economies of other nations over the past 25 years. The volume of world trade increased fivefold during this period, while agricultural trade nearly tripled, growing significantly faster than world agricultural production. The nations of the world now depend heavily upon one another for agricultural raw materials, food, and fiber. The share of exports in the U.S. gross national product more than doubled from 1960 to 1975, with that trend even more pronounced for the agricultural sector. From 1920 to 1962 the United States was a net importer of agricultural products. Today, however, the production of 1 out of every 3 acres of U.S. cropland is exported, and a fourth of farm income is derived from export sales. The United States exports 70 percent of all the corn, 80 percent of all the soybeans, and 40 percent of all the wheat that move in world trade. Our market prices are influenced to an increasing extent by supply and demand conditions in the rest of the world. Closed-economy analysis, which ignores the interrelationships between U.S. agriculture and the rest of the world is no longer appropriate.

OBJECTIVES OF AGRICULTURAL TRADE MODELING

In this survey, as in all such reviews, it is essential to keep in mind the broad objectives of agricultural trade modeling:

- to add to knowledge by helping to understand the real world,
- to test trade theory,
- to provide forecasts, policy and program analyses, and projections to policymakers and other decisionmakers.

The first objective involves clarification of the international trade linkages among countries against the backdrop of an increasingly complex and interrelated world agricultural economy. Models can contribute to understanding the nature of global interdependence and identifying current and emerging problems in world commodity markets. There are large gaps in our knowledge of world market structure not only in the traditional sense of the behavior of producers and consumers, but also with regard to the response of government policies and marketing institutions, such as large trading firms and State traders, to changing conditions in the world market.

A second objective of agricultural trade modeling is to test theory. The rich body of international trade theory, particularly that related to the commodity composition of trade, spatial equilibrium, and commercial policy, serves as a source of hypotheses for empirical testing. The theory suggests which

variables are relevant to include in a model and the manner in which they are related. Quantitative techniques are then employed to confront the theoretical or conceptual model with real world data. If the data are inconsistent with the theory, the theory needs to be modified or extended. If the data are consistent with the theory, this suggests that the theory can be used to predict real world events.

The third objective of agricultural trade modeling is to provide useful forecasts, policy and program analyses, and projections for policymakers and other decisionmakers, such as producers, investors, and market intermediaries. The variables of interest include the U.S. export volume, the market price, supply, and utilization in one or more foreign regions, and the U.S. market share by export destination. Models can provide quantitative estimates (point or interval) of these variables as a basis for decisionmaking. While the same variables are frequently of interest to different groups, the potential users vary considerably in the length of run they are concerned about.

Forecasting is taken here to refer to predictions of what will happen in the short run, up to about six quarters into the future. During the forecasting period, tastes and preferences and the capital stock can be taken as fixed, with only limited possibilities to reallocate land area among crops or to change government policy. Therefore, the structure of demand can be taken as more or less given. Weather, wars, and other acts of God are the principal factors that can alter supply in the short run. Of particular concern to the users of forecasts are shifts in foreign supply associated with changing weather conditions and, in turn, their impact on U.S. market price and export volume by destination.

Policy analysis in trade modeling involves predicting the effects of possible changes in domestic farm policies or in trade policies in the United States or elsewhere on market price, export volume, foreign supply and utilization, and the U.S. market share in each importing nation for a given commodity. For policy analysis, the distribution of costs and benefits from a policy change is also of interest to the decisionmakers. Interest usually lies in the 1- to 5-year time path of adjustment in response to a policy change. While much policy analysis with trade models involves assessing the likely effects of alternative policy options and instruments, it also involves evaluating existing policies and designing more efficient means of achieving the same ends. In international trade, this evaluation requires both identifying the locus of comparative advantage and the extent to which the country is a large trading country and therefore can affect the world market price by its action.

In the 1- to 5-year time horizon, tastes and preferences are relatively constant. The time frame is long enough, however, that farmers can reallocate their land among crops and alter their capital stock through investment, while governments can

substantially alter the existing policies. Since there is sufficient time to reallocate resources in production and alter the product mix demanded in response to changes in relative prices, the critical estimation problem involves measuring the response in supply and demand to changes in relative prices over time. In the trade context, the policy reactions of other governments and the reactions of state trading organizations and of large trading firms to changes in world market price or other countries' policies are also important unknown behavioral relationships. Knowledge of these relationships is essential to estimate the effects of a change in policy, whether it be a U.S. farm program, a trade restriction, a price stabilization scheme, or a food aid proposal. In such analyses, one must either assume normal weather conditions or carry out stochastic simulations to generate a probability distribution of outcomes for the variables of interest.

The longrun projection period is usually at least 5 years. This period is long enough for per capita income and tastes and preferences to change significantly, thereby altering price elasticities of demand, and for technological change to so alter the shape of the production possibilities surface that the supply response to changes in relative prices is also modified. Examples of the types of issues of particular concern here include: longrun projections of the world food supply-demand balance, limits to world agricultural output growth, the effects of global climatic change or of future energy scarcity on agricultural output, and the effects of a major technological breakthrough. Characteristic of most such exercises is extrapolation well out of the historical range of the variables of interest. Frequently such projections are never intended to be predictions of what will actually happen in the future; rather, they serve to alert the decisionmakers to what will likely happen if present trends continue, thereby making them aware of the need for policy intervention to alter those trends.

These three objectives of agricultural trade modeling comprise the criteria by which the recent literature will be evaluated. No one model or modeling approach can be expected to contribute to knowledge, to test theory, to forecast well, and to be useful for policy analysis and longrun projections. That is simply too much to ask. Rather, the extent to which each modeling approach or group of models contributes to one or more of the above objectives will be evaluated.

TWO-REGION MODELS OF AGRICULTURAL TRADE

In two-region models, all countries of the world are divided into two groups: the one of interest (in this case, the United States) and all others. Two-region models are basically domestic agricultural sector models that are open to international trade. They contain explicit export demand or import supply relations and linkages between the domestic and world market prices to reflect the simultaneous determination of domestic supply, utilization, and price with those in the rest of the world. Such models are not trade models in the strictest sense

because they do not account for trade flows (source to destination). Rather, they explain only net trade between the country of interest and the rest of the world. They are treated here because such open-economy models of U.S. agriculture constitute a significant part of the agricultural trade research to date and have been much used for U.S. trade policy analysis and for forecasting.

In this section, a number of attempts to estimate the export demand or import supply equations confronted by the United States are reviewed. Despite the numerous attempts, little consensus has been reached on the sizes of the own- and cross-price elasticities for individual commodity exports or imports. This is partly due to data problems, specification error, and choice of inappropriate estimators. Even with acceptable parameter estimates, such two-region models have limited capabilities. They can only be used to analyze domestic policy issues, as it is impossible to know how to shift the export demand schedule in response to events in individual foreign countries.

Historical Survey

The volume of agricultural exports was treated, prior to the seventies, as an exogenous variable, if included at all, in most U.S. agricultural sector models. For example, Fox's (83) agricultural sector component of the Brookings econometric model of the U.S. economy contained no mention of exports. 1/ Cromarty (60) and Egbert (72) treated the volume of agricultural exports as exogenous in their models. Some variations of the mathematical programing models of U.S. agriculture of Heady and associates still treat exports as fixed exogenously (for example, Meister, Chen, and Heady (166); Heady and Srivastava (102)). The same applies for Hashimoto's (100) quadratic programming model of U.S. agriculture and Arzac's (15) stabilization policy study. With exports given exogenously, the models were, in effect, solved as closed-economy models. The assumption of exogenous exports implies that the United States confronts a perfectly inelastic demand schedule for its exports. That is, export volume is completely unresponsive to price changes, as occurs with binding quantitative restrictions on export volume.

Tweeten (258) demonstrated that this was an unacceptable view of the world. Using Yntema's (273) formula, Tweeten calculated the aggregate elasticity of demand by the rest of the world for U.S. agricultural exports to be on the order of -6.4 to -16. In light of these rather large elasticities, Schuh (225) went to the opposite extreme from the earlier fixed export quantity approach and assumed that the United States is a price taker in the agricultural export market, that is, that it confronts a horizontal or infinitely elastic export demand schedule. Paul Johnson (125) criticized the approach Tweeten used to aggregate over countries to calculate the elasticity of export demand.

1/ Underscored numbers in parentheses refer to items cited in the References at the back of this publication.

Nevertheless, Johnson's own calculated value of -6.7 is within Tweeten's range. Bredahl, Meyers, and Collins (34) argued that both Johnson and Tweeten had taken inadequate account of the degree to which importing countries' policies prevent world market price signals from being transmitted into their domestic economies. Their calculations produce individual elasticities of export demand for the major U.S. agricultural exports that are inelastic or, at most, unit elastic. None of these values were actually estimated econometrically.

Simultaneous with these efforts were attempts by general economists to estimate econometrically the aggregate elasticity of export demand for U.S. agricultural products. These attempts were generally a part of balance of trade analysis or forecasting. 2/ These estimates of the price elasticity of export demand for agricultural products (principally crops) include: Houthakker and Magee (113), -0.96; Clark (52), -0.38; Hooper (107), -0.88; and Hooper and Wilson (108), -1.47. As is apparent from the range of these estimates, these studies reached little consensus on the magnitude of the "true" elasticity. However, the estimates all were substantially smaller than Tweeten's and Johnson's values.

By the midseventies most agricultural economists building U.S. agricultural sector models recognized that the export market's role in domestic price formation had become so great that exports could no longer be effectively ignored by treating them as exogenous to the system. Several U.S. Department of Agriculture (USDA) researchers, as a result, attempted to estimate directly the price elasticity of export demand for the principal agricultural export products. These included studies of corn and grain sorghum by Bredahl, Womack, and Matthews (36), soybeans and soybean meal by Bredahl, Meyers, and Hacklander (35), and wheat by Gallagher, Lancaster, Bredahl, and Ryan (86). The objective of these efforts was to improve the export forecasting and agricultural policy analytical capability of the USDA (Teigen and Womack (247)).

A number of other attempts were made to estimate directly the export demand schedule confronted by the United States in the world market for specific products. These include Meinken (165), Mo (172), and Taylor and Talpaz (245) for wheat; Meilke (163) for feed grains; Houck and Mann (110) for soybeans; Farris (75) for cattle hides; and Roy and Ireland (209) for

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2/ These direct estimates of the export demand elasticity fall in a long tradition in the general international trade literature of estimating aggregate export demand equations for economies as a whole. The motivation for much of that work was to provide elasticity estimates to determine whether the Marshall-Lerner condition, the necessary condition for a devaluation to successfully improve a country's balance of payments, is satisfied in practice. This literature is reviewed in Leamer and Stern (146, ch. 2). See Stern, Francis, and Schumacher (234) for an annotated bibliography.

sorghum. Rather than estimate an export demand equation for wheat, Burt, Koo, and Dudley (38) carried out a Box-Jenkins time series analysis on the gulf export price. Using an independent estimate of the price elasticity of export demand, Konandreas and Schmitz (135) converted a world price-forecasting equation to a demand-forecasting equation. The USDA stochastic grains policy simulators, WHEATSIM (Sharples (227)) and FEEDSIM (Holland and Meekhof (104)) contain nonlinear export demand schedules synthesized from available elasticity estimates. Cochrane and Danin's (54) reserve stocks simulator included supply and demand schedules for the United States and the rest of the world. In studying the effects of altering the levels of livestock product import quotas, Freebairn and Rausser (84) and Novakovic and Thompson (177) avoided the problem of estimating excess supply of the rest of the world for beef and dairy products, respectively, by assuming that the import quotas would not be increased so much that they would no longer be binding.

In addition to these single product studies, a number of open, simultaneous, multicommodity models of U.S. agriculture contain price-responsive export demand schedules for the major U.S. agricultural exports. The econometric class includes Ray (193), Trapp (255), Eckstein and Heien (70), Shei (228), and Chambers and Just (46), which were built for policy analysis or forecasting. The proprietary U.S. agricultural econometric forecasting models, which include Wharton (Chen (49)), Chase Econometrics, Data Resources, Inc. (Scherr (219)), and Evans Econometrics, all include export sectors, but appear to use more ad hoc procedures to project exports and solve the domestic model after substituting in that level of exports. Baumes' (20) separable programming model of U.S. agriculture contains synthesized price- responsive (stepped) export demand schedules. The USDA models, AGSEM (Miller and Washburn (169)) and NIRAP (Quance (187)) both contain synthesized, price-responsive export demand schedules.

Evaluation 3/

The simplest and most straightforward approach to including international trade in models of U.S. commodity markets was to begin with existing closed- economy models in which the quantity exported or imported had been treated as exogenous and to add export equations or excess demand equations for the rest of the world. This was clearly the most expeditious means of taking simultaneities between the world market and the domestic economy into account in econometric models used for policy analysis or forecasting. These efforts have not reached any consensus on the orders of magnitude of the own- and cross-price elasticities of export demand for the principal U.S. agricultural export products. Their contribution to our understanding of the interrelationships between the U.S. and foreign markets has, therefore, been somewhat limited. This failure has also limited the models' utility for simulating the effects

3/ This section draws in part on previous work in Thompson (249) and Williams and Thompson (271).

of policy changes. The lack of generally accepted empirical estimates of export demand elasticities has limited the use of the standard formulas for calculating the incidence and social costs of tariffs and other trade policy distortions, for example, Josling and others (129), Valdes and Hayssen (262), and Cline and others (53) .

Each of the studies reviewed made an ad hoc decision on whether to assume the United States to be a large or small trading country in the world market for the commodity of interest. If the U.S. market share is small relative to the total volume traded on the world market, the country could be considered a price taker, confronting a horizontal world market demand or supply schedule. As long as there are no quantitative restrictions to trade, the domestic price equals the world market price plus or minus any taxes, subsidies, and marketing and transportation costs. To analyze policy, this is the simplest approach, and it greatly facilitates the analysis. For purposes of forecasting, this is more complicated, since it is a more difficult task to forecast the world market price than the export volume.

If U.S. exports or imports represent a significant part of world trade in the commodity of interest, the world market price cannot be taken as exogenous. Rather, the domestic and world market prices are determined simultaneously. In such cases, the parameters of the excess demand or excess supply schedule of the rest of the world must be estimated.

The treatment of U.S. agricultural exports as exogenous, with no price responsiveness, appears inappropriate in light of the relatively large market shares cited previously. It would be worthwhile, nevertheless, to test explicitly the small open-economy hypothesis in the case of certain agricultural exports rather than making an ad hoc decision on whether or not to estimate an export demand schedule. This might be done by a procedure such as the test of the small open-economy hypothesis for aggregate exports and imports developed by Appelbaum and Kohli (12). This approach applies duality principles to noncompetitive markets and provides an explicit parametric test of the price-taking hypothesis. The test considers the economy's equilibrium as characterized by the solution to a profit maximization problem. They assume, however, that rather than confronting given export and import prices (the small country case), the firms in the economy face supply and demand functions for the country's imports and exports. Given this maintained hypothesis, they test whether the market prices of imports and exports are equal to their corresponding shadow prices.

For forecasting, reduced-form export equations may be very useful, although no evaluation of the forecasting performance of any such export equation was found in the literature. The only published attempt to employ time-series techniques, like Box-Jenkins, for export forecasting is Burt, Koo, and Dudley (38). When attempting to estimate Box-Jenkins monthly forecasting

models for U.S. corn and wheat exports, in unpublished work Magiera found that with the exception of 12-month seasonal lags, all other lags in the models were quite short (2 to 3 months) and oscillations decayed rapidly. In light of the year-to-year volatility of exports due to changes in worldwide weather conditions, this suggests that such models may be most useful for forecasting in the very short run. The most common technique employed for export forecasting seems to be expert opinion, not models, but there may be some payoff from composite forecasts based on both expert opinion and time-series techniques.

To analyze the effects of changes in domestic farm policy or U.S. trade policy, a model that contains well specified and estimated export demand and import supply equations for the important traded commodities may be adequate. Such an approach, however, has severe limitations in estimating the effects of changes in trade policy by other countries in the world market. An equation of excess demand of the rest of the world (ROW) attached to a U.S. market model represents the net effect of all supply and demand adjustments in all other trading countries. That is, an excess demand equation represents the horizontal summation of the domestic supply and demand schedules of all other countries in the world market--exporters and importers alike. Prior to horizontal summation, the price arguments of all supply and demand schedules must be converted to a common currency, U.S. dollars in this case. In addition, all tariffs, subsidies, and transport costs that shift or rotate the excess supply and demand schedules relative to each other must be taken into account before summation. Instead of horizontally adding in the domestic supply and demand schedules of those countries that impose quantitative restrictions or variable levies, which cut the link between domestic and world prices, a vertical excess demand schedule at the equivalent quantity should be added instead. 4/

Any change in an exchange rate, tax, subsidy, quota, or freight rate shifts or rotates the excess demand schedule confronted by the United States. Without knowledge of the structure of supply and demand in each important trading country, one cannot tell how to shift the excess demand schedule in response to any given shock or policy change. This approach has severe limitations for evaluating the effects on the U.S. market of policy changes in other countries. For this purpose, it is necessary to disaggregate the export demand schedule and go to a multiregion trade model. Such a model is treated later in this report.

Models designed for agricultural trade policy analysis tend to treat only one commodity at a time and abstract from

4/ Tweeten (258, 259), Cronin (61), and Bredahl, Meyers, and Collins (34) demonstrated how quantitative restrictions in importing countries reduce the elasticity of export demand confronting an exporter like the United States.

significant simultaneities among the grains, oilseeds, and livestock sectors in supply and demand. Paarlberg and Thompson (180) demonstrated that it takes no more complex a world than two countries and two commodities related to each other in supply and demand to turn the sign of the effect of an import tariff on own-price in the importing country indeterminate. 5/ The effect of a tariff depends on the magnitudes of the cross-price effects relative to the own-price effects. That is, it is an empirical question. This result illustrates the importance of obtaining unbiased estimates not only of the own-price elasticity of export demand, but also of the cross-price elasticities if one is to avoid erroneous predictions of the effects of a change in trade policy. This is particularly important for grains and oilseeds because there are significant substitution possibilities in both supply and demand. While there is little consensus on the orders of magnitude of the own-price elasticities of export demand, there is virtually no evidence on the magnitudes of the cross-price elasticities of export demand for U.S. agricultural commodities. The prices of other commodities have rarely been included in the specification of the export demand schedules estimated, except in the USDA Forecast Support Group models (Teigen and Womack (247)).

Two econometric problems pervade much of the empirical work that has attempted to directly estimate agricultural export demand equations 6/--specification error and simultaneous equation bias. Both may lead to biased estimates of the elasticity of export demand.

Specification error in an export demand equation involves omitting relevant variables and including extraneous variables as arguments of the function. Omission of relevant variables can result in biased estimates of the coefficients of variables included in the equation, as well as biased estimates of the variances of those coefficient estimates. The inclusion of extraneous variables in the equation can lead to a loss in efficiency (182, pp. 187-191). Specification error often enters export demand equations through a failure of the analyst to recognize the exact nature of an export demand equation. As explained above, all shifters of the domestic supply and demand

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5/ This result is similar to the Metzler paradox in the pure theory of international trade. Working with the two-by-two-by-two general equilibrium model of trade, Metzler (168) demonstrated that, under certain conditions, imposition of an import tariff by one country may so depress the world terms of trade that the price of the "protected" good in the importing country falls as well.

6/ Analogous arguments apply in the case of import supply equations of the rest of the world to the United States, but they will not be made here in the interest of economy of presentation. In addition, many of the comments made here are equally relevant for many of the multiregion models discussed later in this report.

schedules in all other trading nations are variables in a U.S. export demand equation. In many of the export demand studies surveyed, relevant variables are omitted. The price in one country is often used as a proxy for the internal price in the entire rest of the world without accounting for changes through time in the relationship between that "representative" price and the prices in other countries. The resulting parameter estimates are, therefore, likely to be biased.

Specification error also occurs when arguments of the U.S. supply and demand schedules are included as variables in an export demand equation. It would be more appropriate to call such equations, "export equations," not "export demand equations." A common example involves the inclusion of the U.S. market price as a proxy for the world market price in an "export demand equation." The U.S. price is an adequate proxy for the world price paid by foreign importers only if exchange rates, transport costs, and all taxes, subsidies, and other policy interventions have been constant through the period of the data. These conditions certainly did not hold through the seventies. Attempts have been made to partially circumvent this problem by including the exchange rate for the U.S. dollar relative to a basket of foreign currencies either in a multiplicative fashion or as a separate variable (Bredahl, Gallagher, and Matthews (33), Chambers and Just (45)). Nevertheless, it may simply be asking too much of a single export demand equation to adequately reflect the myriad forces that shift it from year to year. Many attempts, mostly unpublished, at direct estimation of export demand equations have given weak results, probably due to this problem (e.g., Williams and Thompson (271), Sarris (214)).

The second econometric problem with most attempts to directly estimate export demand schedules is simultaneous equations bias. Most have been estimated by ordinary least squares (OLS) when a limited or full information estimator, like two- or three-stage least squares (2SLS or 3SLS) would have been more appropriate. The problem here is that when one specifies a price responsive export demand equation, one assumes that the export volume and world market price are simultaneously determined with domestic prices and quantities. Therefore, the price argument (and any other endogenous variables included on the equation's right hand side) are jointly determined with the error term of the export demand equation. Application of ordinary least squares in such cases results in biased

parameter estimates. 7/ A limited or full information estimator, which purges the right hand side endogenous variables of the stochastic component associated with the error term, is needed to obtain consistent parameter estimates.

While the parameter estimates obtained by using a simultaneous systems estimator converge to the true parameter only for large samples, Monte Carlo studies have shown that OLS estimates generally display greater small sample bias (128, p. 410). This seems to imply that, even for small samples, the use of a limited or full information estimator like 2SLS or 3SLS is always a more appropriate procedure. Binkley and McKenzie (27) demonstrated for the two-country case that the bias in the price coefficient of the export demand schedule confronted by the United States is greater, the greater the absolute values of the price coefficients of the U.S. excess supply schedule and the excess demand schedule. The bias also varies with the ratio of the variance around the excess demand schedule to the variance around the excess supply schedule. Binkley (25) has shown that it is really the relative variation around the functions and not their slopes that determines the level of bias. The larger the random shifts in the U.S. excess supply schedule relative to those of the ROW excess demand schedule, the smaller will be the OLS bias. To illustrate this, Binkley and McKinzie (27) carried out a Monte Carlo comparison of the performance of three alternative estimators of an export demand schedule in a two-region trade model. The three estimators compared were: OLS, 2SLS, and "analytical least squares" (ALS). The last involved estimating the domestic supply and domestic demand schedules in the rest of the world by 2SLS and then analytically deriving the associated excess demand schedule.

The major results of their study were that if the variation around excess supply is "significantly greater" than that

7/ Already in the early fifties Orcutt (178), Machlup (150) and Harberger (95) had argued that direct estimation of an aggregate export demand schedule by OLS would bias the estimated price coefficient downwards. To this, Orcutt added four other reasons why many empirical estimates of the price elasticity of export demand were biased downwards: random observation errors in the price indices, aggregation (he was concerned with the export aggregate), timing (shortrun elasticities are smaller than longrun elasticities), and quantum effects (elasticities are larger for large price changes than for small price changes). Magee (156, pp. 214-218) countered with a list of reasons why empirical estimates of the price elasticity of export demand might be overstated: nonprice rationing, cross-price effects, structural effects, understated lags, inversely correlated measurement errors, aggregate prices in submarkets, positive component elasticities, and what he termed, "Orcutt-ization" to refer to the subjective upward bias imposed by econometricians on those elasticity estimates they published in the years following Orcutt's paper.

around excess demand, use of OLS to estimate the latter does not appear to lead to serious econometric problems. Indeed, OLS was superior to the consistent methods in some cases. When the pattern of variation was reversed, however, the consistent methods clearly outperformed OLS, with ALS slightly better than 2SLS. In some cases, the OLS estimates were "spectacularly" poor. These results suggest that when U.S. excess supply has a large variance relative to excess demand, OLS may be the preferred technique for estimating the export demand schedule. However, at least in the cases of wheat and feed grains, the variation in export demand exceeds that of U.S. excess supply. In such cases a limited or full information estimator is called for, with a dissagregated approach, as in ALS, being preferred.

Since open economy simultaneous models tend to be quite large, one complication often arises when using limited or full information estimators to estimate the export demand schedule. The number of exogenous and predetermined variables in the system often exceeds the number of observations available in the data set. 8/ This makes it impossible, for example, to employ 2SLS because, in the first stage, each endogenous variable is regressed on all exogenous and predetermined variables in the system. This problem has often been handled in the past by replacing the matrix of exogenous and predetermined variables with a smaller number of principal components in the first stage (following Kloek and Mennes (133)). Recently, however, the more generally accepted procedure has been to employ the Iterative Instrumental Variables (IIV) method to arrive at a smaller number of instruments in the first stage (see, for example, Fisher and Wadycki (80) and Brundy and Jorgenson (37)).

Summary and Implications

Two-region models have achieved only limited success in contributing to the objectives of agricultural trade modeling. In light of their failure to reach any consensus on the magnitude of the price elasticity of export demand, the most critical parameter in such models, they must be judged to have contributed little to our understanding of the interrelationships between the U.S. and world markets. Few of the studies were concerned with testing trade theory explicitly; the objective of most studies was forecasting or policy analysis. It appears that some export equations have functioned reasonably well for forecasting export volume in the short run. This observation, however, is based on anecdotal evidence: no documentations of forecasting performance out of the range of the data used to estimate the equations were found. Longrun projections of the volume of U.S. agricultural exports have been almost universally too low. Attempts at forecasting export price have been fewer and apparently less successful than those forecasting

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8/ It should be borne in mind here that the set of "all exogenous and predetermined variables in the system" includes all the domestic supply and demand shifters in the rest of the world, as well as in the country of interest.

export quantity. Efforts have been focused more on forecasting the internal market price, with a given export volume.

While many of these modeling efforts had the stated objective of contributing to policy analysis, the contribution of most has been limited. Without reliable and unbiased estimates of the price elasticities of export demand for the principal agricultural commodities, one cannot put much faith in the policy analyses based on such models. Despite the weak empirical estimates, few studies carried out adequate sensitivity analysis to demonstrate how sensitive the conclusions reached were to the values of the parameter estimates.

Even with acceptable parameter estimates, the only types of policy that two-region models can be used to analyze are domestic farm policy and U.S. trade policy, because it is impossible to tell how to shift the export demand function in response to a policy change in any individual foreign country. Moreover, two-region models provide no information on supply and disappearance in individual foreign countries or on the U.S. market share by export destination. For such questions, it is necessary to disaggregate the structure behind the excess demand schedule of the ROW and go to a multi-region simultaneous model in which the individual regions are linked through trade flows and prices are linked through transportation costs, taxes, and subsidies (except when quantitative restrictions, which cut the price link, are imposed). This class of models is treated in the next section.

MULTIPLE-REGION MODELS OF AGRICULTURAL TRADE

Multiple-region models of agricultural trade emphasize interrelations or simultaneities among countries through world trade. Here the aggregate rest of the world region of the two-region models is divided into two or more trading regions. Each region may be an individual country or a group of countries, usually contiguous, with relatively homogeneous agroclimatic conditions, level of economic development, and policy interventions. All regions are assumed to be large trading regions, that is, the actions of each region acting independently can affect the world market prices for its imports or for its exports. Nevertheless, most models assume that agricultural production and marketing are characterized by a large number of small firms, each of which is a price taker or perfect competitor.

Each region is represented in the model by an export supply or import demand schedule for each commodity, or by a model of its

internal supply and demand structure, which implicitly accounts for the region's export or import behavior. 9/

Three basic classes of trade models include multiple regions: nonspatial price equilibrium models, spatial price equilibrium models, and trade flow and market share models. Most are partial equilibrium models that treat one commodity at a time, although some models treat more than one commodity simultaneously. The three classes differ principally in the nature of the price linkages among trading regions and in the mathematical procedure used to solve the models, as the empirical estimates required in each of the three classes is very similar. Each solution procedure imposes a different set of restrictions on the behavior of the variables in the model. These differences affect the relative abilities of the approaches to contribute to one or more of the objectives of agricultural trade modeling defined above.

Nonspatial Price Equilibrium Models

Nonspatial price equilibrium models are the simplest multiple-region trade models. They explicitly treat the interrelations among trading regions by assuming that the world market price is determined simultaneously by the supply-demand balance in all trading regions such that the global market clears. The model solution gives the world market-clearing price(s) and net trade of each region trading in the world market, but it provides no information on source-destination trade flows.

All models in this class are comprised of systems of equations that are solved by matrix inversion, if linear, or by an iterative procedure, such as the Gauss-Seidel or Newton-Rafson technique, if nonlinear. Three subclasses of nonspatial price equilibrium models differ in the nature of the price linkages among the trading regions. The first subclass assumes the existence of one global market-clearing price (often the U.S. domestic or export price) at which all international

9/ One important distinction from the last section must be made clear at the outset. That section was concerned with estimating the aggregate excess demand (or import supply) schedule of the rest of the world confronted by an individual trading country. Here, the focus is exactly reversed. Of concern here is each individual region's export supply or import demand as perceived by the rest of the world. Failure to grasp this distinction at the outset will lead to considerable confusion in following the ensuing argument. The export supply or import demand "schedule" may, where appropriate, be a fixed quantity that does not respond to changes in world prices for certain countries.

transactions occur. This approach abstracts completely from the spatial pattern of prices associated with freight rates. 10/

In the second subclass, the commodity prices in all but one region in the model are linked through transportation costs to the price in the nth region, which is often the United States. This approach explicitly recognizes that in spatial equilibrium, prices differ among trading regions by exactly the transport cost. The approach ignores the fact that, by the Kuhn-Tucker conditions of spatial equilibrium, these price linkages hold only between pairs of countries that actually trade with each other. There is no theoretical basis for directly linking the prices of two countries that do not trade with each other, such as two exporters.

Those linkages are recognized in the third subclass, which is made up of models that link prices through transport costs pairwise along the principal historical trade flows. This produces a web of price linkage equations (one less than the total number of trading regions in the model). While this subclass does introduce a spatial pattern of prices, it differs in one essential manner from the spatial price equilibrium models: models in this subclass generate only the net trade position of each trading region, while the spatial price equilibrium models generate source-destination trade flows endogenously in the model.

Nonspatial price equilibrium models generally include more domestic market detail and are often better validated than other multiple-region models. While tariff policies can be easily reflected in such models, most have an exaggerated free trade bias. Some important contributions have been made to reflect the policy environment in which trade occurs via policy reaction functions and price transmission equations. Nontariff barriers to trade, which dominate agricultural commodity markets, have been more difficult to reflect in nonspatial price equilibrium models than have tariff policies. Development of these models, nevertheless, has improved our understanding of the interrelations among different countries' agricultural sectors through world trade.

Historical Survey

There is no natural historical progression of the applications of the three subclasses of nonspatial price equilibrium models. All three were used throughout the seventies, although only the first two have had extensive applications.

10/ This does not, however, preclude the modeler from introducing tariff barriers to trade by shifting or rotating individual countries' export supply or import demand schedules. Nontariff barriers to trade can be introduced in the form of quantitative restrictions if an iterative solution procedure such as Gauss-Seidel is employed. These techniques put a "wedge" between the domestic price and export or import price.

Coffin (55) pooled time series data on 30 countries in an attempt to estimate a cross-country import demand schedule for wheat and flour. He, in effect, assumed that the same world market price confronts each importing country in its port. Honhon (106) estimated a system of equations to explain the export behavior of the principal corn exporters, assuming the same world corn price was faced by all exporters. He estimated an export demand schedule for corn from the United States in price dependent form. Adams' world oils market model (4), which was designed for forecasting, determines a global oils price to which the world price of each individual oil is linked. Reutlinger's (197) stochastic simulator for global grain reserve stocks derives one world wheat price from the intersection of world supply and demand schedules. Adams and Behrman's three-region "mini-models" of seven world commodity markets (7) assume that one world price clears the market for each commodity. The same procedure was applied in Collins, Evans, and Barry's world cotton model (59). Wong (272) added regional import demand schedules to the Danin, Sumner, and Johnson (62) optimal grain reserves model, taking the U.S. export unit value for grains as the world market price confronted by each importer. The MSU Agriculture Model (Mitchell and Armstrong (171)) takes the U.S. export prices of wheat and coarse grains as the world market prices faced by the five importing and four exporting regions included in the model. Arguing that transport cost differences are implicitly included in the intercepts of the various regions' export supply and import demand schedules, Zwart and Meilke (276) specified one world market price in their model of the world wheat market as did Griffith (93) for each commodity in his model of the world rapeseed and soybean markets.

In the second subclass of nonspatial price equilibrium models the prices in all regions but one in the model are explicitly linked through transport costs to that in the nth region. In some examples, the price to which all other regional prices are linked is the "world market price." In the FAO World Price Equilibrium Model (82), all national prices for 18 commodities in 28 regions are linked to world market clearing prices or a world market price index. This nonlinear model is solved for static equilibrium solutions. The Japanese Ministry of Agriculture's 11-commodity, 25-region projections model (119) links national prices to a world market clearing price. For lack of data, the world price is also assumed to be the domestic price in several of the trading regions. This nonlinear model is solved recursively for the time path of adjustment of all endogenous variables, including stocks. A similar procedure is used in Tyers and Setboonsarng's model which includes 21 regions and 4 commodities (260). Leontief and others (147) have built a 15-region, 45-sector world input-output model for the United Nations. Among the 45 sectors are four agricultural sectors: grains, high protein crops, livestock, and root crops. The prices in each of the other regions are linked to U.S. prices, which are in turn determined by value-added functions. A similar procedure is followed in Bottomley's 60-sector world input-output model (31).

Williams' world soybean and derivatives market model (270) aggregates all importers into one region and links the prices of soybeans, soy meal, and soy oil back through transport costs and policy distortions to internal prices in Brazil and the United States. The world grains market models of Abbott (1) and Sarris, Abbott, and Taylor (215) are solved for one global market-clearing price, which is linked indirectly through policy reaction functions that explain import and export volumes to the internal market prices. A similar approach was used by Chaipravat (44) in modeling world rice trade. Lattimore and Zwart's (145) world wheat market model links the prices in all other regions to the U.S. Gulf price. Similarly, Kost, Schwartz, and Burris's (137) net trade forecasting models for wheat, coarse grains, and soybeans generate world market clearing prices to which national prices are linked. The Food and Agriculture Model of the International Institute for Applied Systems Analysis (Keyzer (130, 131), Fischer and Frohberg (78)) is a 20-region, 19-product general equilibrium model in which world market-clearing prices are determined by means of a nonsmooth, nonlinear optimization solution procedure. National prices are linked through policy reaction functions to the world market-clearing prices. The IIASA model is the second generation of the Model of International Relations in Agriculture (MOIRA) in which all agricultural output was aggregated into protein equivalent units and which determined an equilibrium world market "food price" (Linnemann and others, 149).

The last subgroup of models in this class includes pairwise price linkages among countries along the principal historical trade flows. This modification to the usual approach to nonspatial equilibrium modeling outlined above was made in building the USDA's Grains-Oilseeds-Livestock (GOL) Model, a 12-commodity, 28-region model of world agriculture built for long-term projections (Rojko and Schwartz (204), Rojko and others (206, 207)). The same basic approach had been adopted earlier by USDA for building world trade models for grains (Rojko, Urban, and Naive (205)), oilseeds and oilseed products (Moe and Mohtadi (173)), and rice (Moriak, Strickland, and Grant (175), Grant, Mullins, and Morrison (89)).11/ The same basic properties of the GOL model carry over into its integration with the NIRAP model (National Interregional Agricultural Projections) (Quance (187)) discussed above and the World Integrated Model (WIM) (Mesarovic and Pestel (167)) in the Agricultural and World Integrated Model (AGWIM) to provide a general economic model with emphasis on food and agriculture (Quance and Mesarovic (188)).

Evaluation

Nonspatial price equilibrium models comprise the simplest class of multiple-region agricultural trade models. They are

11/ The frequent confusion over these USDA models being spatial equilibrium models is compounded by the fact that they are solved by a linear programming algorithm. However, the linear programming code is employed merely to solve simultaneously a large system of linear equations.

basically sets of regional models each composed of a system of simultaneous equations. The prices in all regions are linked together, and the models are solved simultaneously, subject to the condition that the world market has to clear, that is, global excess supply has to equal global excess demand. The focus in all such models is on the interrelationships among the trading regions for purposes of achieving one or more of the objectives defined in the introduction to this report.

If a model is to contribute to understanding the interrelations among countries, or to be useful to decisionmakers, its empirical content must faithfully reflect the essence of the structure of the markets of the regions linked through international trade. This includes not only the structure of internal supply and demand, but also government policy behavior and the competitive structure of the industry.

The majority of the studies surveyed in this section contained internal supply and demand schedules of the trading regions, although several contained only an export supply or import demand schedule for each region. Several were estimated by a limited or full information estimator, although more were estimated by ordinary least squares. Of those in the former category, relatively few included rest of the world instrumental variables in the first stage estimation. The same criticisms that were made of two-region models, with respect to simultaneous equations bias, are equally applicable here. Biased parameter estimates contribute little to understanding the phenomenon of interest or to policy analysis.

When reviewing most nonspatial price equilibrium models, one is impressed that much more emphasis has been put on model specification and solution technique than on the empirical content. Frequently, no validation statistics are reported for either a base year or for the model's tracking ability through time. There are few examples in which the plausibility of the estimated coefficients was evaluated. In most cases, the authors only checked the signs and t-values of the coefficient estimates, without examining whether the magnitudes of the estimates made any sense in light of the real world phenomenon being modeled.

It can be a tedious, time-consuming, and often very expensive task to build a world trade model for even a single commodity because there is no one place where all the requisite data on other countries is conveniently available. Both FAO and the USDA collect, evaluate and publish data on physical area, yield, production, imports, and exports of the grains. No organization worries about documenting internal market prices and policy interventions for all countries with the same care. Data on stocks of all commodities, livestock herd size, pasture, and oilseeds and derivatives quantities and prices are all much spottier and less reliable, where available, than for the grains. This means that the researcher often has to invest a great deal of time and resources to find the needed time series from published and unpublished national sources. Some

necessary data may not even exist, and the quality of what one does find may be suspect. Nevertheless, until some organization begins to collect, evaluate, and bank these data, the analyst has no recourse but to expend the necessary resources on this task. Relatively few of the studies reviewed reflect adequate attention to this very fundamental concern.

One important potential source of information, including structural parameter estimates, on many countries of the world, appears to have been overlooked by agricultural trade modelers. This is the relatively large number of national agricultural sector models that have been built, particularly for development planning or for policy and program analysis. The U.S. Agency for International Development has funded the construction of a number of these for developing countries: South Korea and Nigeria (by Michigan State University), Tunisia (by the University of Minnesota), Colombia and the Philippines (by USDA), Thailand (by Iowa State University), and Senegal and Guyana (by Purdue University). The World Bank has built agricultural planning models for Mexico, Ivory Coast, South Korea, Portugal, Northeastern Brazil, Zambia, and the Central American Common Market. Many national organizations have built agricultural sector models: Canada, West Germany, Australia, United Kingdom, Brazil, Japan, France, and Denmark. The USDA has also been recently estimating agricultural sector models for a number of U.S. export destinations and competitors in the world market (Bale (<u>17</u>)). The accumulated knowledge in these studies should serve as a valuable source of information on individual countries in building a world trade model.

If we are to understand world agricultural trade, we have to understand the structure of the country markets linked through trade. Country market studies appear to have been ignored for this purpose by agricultural trade modelers, with one significant exception. The International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria, is now coordinating the construction of a world food and agriculture model, as cited above (<u>130</u>, <u>131</u>). The approach being taken there is to enlist national researchers in each of the 20 principal agricultural trading countries (including the European Community as one "country") to build and maintain a national agricultural sector model that satisfies certain linkage conventions with respect to product definition and units of measurement. IIASA itself has built a flexible solution mechanism, which resides on its computer, to solve the individual models together for global equilibrium. The logic of this approach has great appeal as a potential means of improving the empirical content in trade models. Much more use could be made of existing national sector models to improve the empirical content in other agricultural trade modeling exercises.

Many of the models surveyed in this section are partial equilibrium models that treat only one commodity in isolation from all others. As discussed in the case of two-region models, omission of relevant variables in the model specification can cause biased parameter estimates, and lead to erroneous

predictions of even the direction of response to a change in policy. This provides the rationale for models that include several commodities simultaneously. The agricultural trade researcher must always be wary of ignoring significant simultaneities among subsectors, particularly among the grains, oilseeds, and livestock sectors. The world is general equilibrium in nature, and ultimately everything does depend on everything else. In policy analysis, the existence of simultaneities among commodities in supply or demand and how these differ among countries are important elements of understanding how the trading regions interact with one another.

In empirical research, the analyst has to impose separability at some point, after which the prices in all other sectors are assumed exogenous. In practice the "correct" point at which to do this may be difficult to determine. The researcher must ultimately rely upon individual judgment as to when the exclusion of a given sector or variable from a model will not appreciably affect the results for the sector(s) of interest. When one begins to model several interrelated commodities in several countries simultaneously, a model quickly becomes very large, and large models are cumbersome to use and expensive to keep up to date. Turn-around time increases. It becomes difficult to tell the difference between a programming error and an unanticipated general equilibrium effect. There are important tradeoffs between large models rich with data and empirical content and small, inexpensive models that can give adequate approximations with quick turn-around.

A model does not have to be large to be sophisticated. Investment of time in theoretical and analytical work prior to collecting data can lead to a model specification that may be much more efficient at accomplishing a specific objective than building a huge multisector simultaneous world model, without compromising the integrity of the results. In principle, it is even possible to estimate general equilibrium supply and demand schedules that embody the net effects of simultaneities with omitted sectors as well as real income changes, although it is difficult to find examples in the literature surveyed. It is useful for some fraction of the agricultural trade modeling resources to be expended on the larger, multicommodity models, if for no other reason than to detect where significant simultaneities exist which, if ignored, would cause partial equilibrium analysis to reach erroneous conclusions.

Those models that include one world market price assumed to hold everywhere, such as the U.S. price, abstract from the spatial pattern of prices associated with transport costs. Freight rates for bulky commodities, like grains, are not an inconsequential part of the landed price in an importing country. If the U.S. dollar price is used as a proxy for the internal price in other countries, this abstracts from the fact that not only freight rates, but also exchange rates and taxes and subsidies on trade change through time. As they change, the relationship between the internal price in another country and that in the U.S. market changes. If one's objective is to

predict the effect of, say, a policy change on foreign supply and disappearance, the result can be distorted by these changes. For forecasting, it appears that models that assume one world market price have performed adequately. The cost of adding greater detail in a forecasting model may not be compensated by improvements in the quality of the forecasts.

Most nonspatial price equilibrium models take an excessively free trade view of world agricultural markets. In reality, most countries intervene actively in their domestic agricultural sectors through a variety of price policies, taxes, and subsidies. When the internal market price is distorted away from the price at which the good could be exported or imported, some form of trade policy intervention is necessary to "validate" the administered domestic price. These trade policies may include tariffs or subsidies that put a "wedge" between domestic and world market prices, but still permit world price fluctuations to be transmitted into the domestic market, albeit in a distorted manner. However, the more common form of agricultural protection is through nontariff barriers to trade, which in effect cut the link between domestic and world market prices. These may take the form of quotas or variable levies. Most of the models surveyed took inadequate account of the effects of these on agricultural trade.

Tariff barriers to trade are easily introduced into a simultaneous equations model in the price linkage equations. This is an important asset of this type of model. A policy change, in effect, changes the length of the link between two regions' prices just as a change in freight rate does. Nontariff barriers to trade are either explicitly or implicitly quantitative restrictions which, in a mathematical programming context, would be introduced as linear inequality constraints. 12/ When binding, the related price linkage no longer holds (Kuhn-Tucker condition). While there is no way to introduce such constraints when solving a linear model by matrix inversion, they can be introduced via "if" statements in an iterative solution technique, e.g., Gauss-Seidel or Newton-Rafson, which can be used to solve either a linear or nonlinear model. This provides one argument for avoiding matrix inversion as a solution technique even if the system of equations that comprises the trade model is linear. Given the facility with which policies can be introduced into a trade model with the presently available solution techniques, there is no excuse for failing to include the relevant policy variables in a model.

While policy variables can be readily introduced in a trade model and parametrically varied to evaluate their effects, for some purposes this is not the most appropriate procedure. There is considerable evidence accumulating that government policy decisions are not completely exogenous to the commodity

12/ A variable levy has the same effect as a quota in cutting the link between the domestic and world market prices. Therefore, it is included in a trade model by its quota equivalent.

markets, e.g., Abbott (1), Zwart and Meilke (276), and Lattimore and Zwart (145) on world grains market policies, Rausser and Freebairn (190) on U.S. beef import policy, Bautista (21) on Philippine food import policy, Lattimore, Schuh, and Thompson (144) on Brazilian beef and corn export policy, and Gulliver, Williams, Thompson, and Revelt (94) and Griffith (93) on Brazil's soybean, soy meal, and soy oil export policy, Anderson (10) on Australian policy, Rausser and Stonehouse (192) on Canadian dairy policy, and Reed and Ladd (194) on feed grain import policy in selected countries. 13/ While the imports of centrally planned economies are usually fixed exogenously in trade models on the argument that they are not determined by a price mechanism, McCalla in (160) has suggested that a unit elastic import demand may be more appropriate, if there is only a given amount of foreign exchange available for grain imports. Brainard (32) has provided evidence that agricultural policy cycles in centrally planned economies, which in turn affect their import decisions over time, can be explained by an economic model. The same might hold for developing countries under foreign exchange rationing. Support for this has been found by Valentini and Schuh (264), Valdes and Huddleston (263), Islam (116) and Bautista (21).

It is not difficult to endogenize policy variables by including policy reaction functions in a nonspatial equilibrium trade model that is solved by an iterative procedure. For example, the level of a policy variable can be made a function of the export price or export revenue, as in Lattimore and Zwart (145). The endogenous policy variable then affects the domestic price through the price linkage equation. Alternatively, one can estimate price transmission equations, following the suggestion of Bredahl, Meyers, and Collins (34), in which the domestic price is made a function of the world price, the exchange rate, and other variables hypothesized to explain variation in the level of the policy variable. 14/ In effect, one is estimating the price linkage equation. The coefficient of world price is a measure of the average extent to which variations in world market prices were transmitted into the domestic market over the period of the data, regardless of whether the policies imposed were tariff or nontariff barriers to trade. The other arguments of the price transmission equation are variables hypothesized to account for changes through time in the size of the transmission coefficient. This procedure has been followed by Collins (58).

13/ For an overview of studies that include endogenous policy interventions, see Rausser and Lattimore (191).

14/ There is some debate in the literature over whether the exchange rate should be included in a multiplicative fashion or as a separate variable. See Bredahl, Gallagher and Matthews (33) and Chambers and Just (45). Fletcher, Just and Schmitz (81) and Meilke and de Gorter (164) have provided evidence that an exchange rate change has a proportionately greater effect on exports than the same percentage change in world price.

The price transmission coefficient is really the average tariff equivalent of the whole constellation of policy interventions employed by a country. 15/ Recognizing that every tariff has a quota equivalent, one can also estimate the policy reaction function with import volume as the dependent variable in place of domestic price. All other arguments of the function are identical. In this case the policy reaction function explains import quantity and the domestic price adjusts to ensure that domestic supply, plus net imports, equals domestic disappearance. When domestic price is the dependent variable, this price then feeds into the domestic supply and demand schedules, which determine net imports as a residual. Abbott (1) and Zwart and Meilke (276) have estimated policy reaction functions in trade quantity dependent form.

These developments have made the specification of trade models more consistent with the real world. The common assumption of unchanging policy intervention levels of most previous models was rarely borne out in practice. The new approach is also useful in policy analysis models to reflect the reactions of other governments to any change in one country's trade policy by altering the levels of their policy interventions. For example, if a large importer is levying the optimum import tariff as suggested by Carter and Schmitz (43), any policy change elsewhere would lead to a recalculation of the optimum tariff. This is one area where research in the last decade on nonspatial equilibrium models has made an important contribution to knowledge of the interrelationships among trading countries. It is also an area where the theoretical free trade model was confronted with data and found wanting.

Two other variables in the price linkage equation, exchange rates and freight rates, are usually assumed exogenous in trade models. Nevertheless, under certain conditions one or both of these variables should be endogenous to the system. At least in years of unusually large volumes of world grain trade, ocean freight rates are clearly not exogenous to the system. Rather, they are simultaneously determined with the volume of grain moving in world trade (Binkley and Harrer (26)). One could, in principle, endogenize the freight rate term in the price linkage equations by adding a reduced form equation that relates the freight rate to the total volume of grain moving in world trade in a model solved by an iterative solution procedure. There is no known attempt to do this in the literature.

The exchange rate is usually assumed to be exogenous in agricultural trade models, despite the world's quasi-floating

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15/ In another sense this can be interpreted as the extent to which world price changes are "passed through" to the domestic market by the marketing system. Magee (155, 157) has argued that the pass-through from exchange rate change has much to do with contract terms, timing of shipment, etc. It may also reflect imperfectly competitive behavior where monopoly or monopsony forces are permitted to function.

exchange rate system. An unchanging rate requires that the value of trade in the commodity of interest be insignificant relative to the total value of international transactions on current and capital account in all the countries in the model. If this condition is not met, the currency of an importing country would tend to depreciate relative to that of an exporting country, as the total value of bilateral trade in the commodity increases. Recent work by Cheng (50) and Chambers and Just (46) has shown, for example, that the U.S. dollar exchange rate has been sensitive to changes in the value of agricultural exports. Their work suggests that a reduced form equation that links the value of exports to the exchange rate could be added to a model solved by an iterative technique.

Most trade models in this class are either shortrun or longrun static equilibrium models. For many purposes, however, the user needs to know the time path of adjustment of certain variables. Where this is important, the response lag structure needs to be built in to permit the model to be solved recursively through time or to be optimized over time. This is particularly important where supply response involves a capital stock adjustment, as in perennials and livestock. Jarvis (120), for example, has shown that the shortrun effect (impact multiplier) of an increase in the price of beef, for example, on supply (slaughter) is negative, turning positive only through time. If the trade analyst is interested in the time path of adjustment in response to a shock or policy change, the model must be capable of exhibiting this type of behavior. Only if one is interested just in the longrun full-equilibrium adjustment is this aspect less important. Of the studies surveyed, Jeon (122) focused on the dynamics of the world wheat market, the Japanese Ministry of Agriculture (119) and IIASA models are solved recursively with supply a function of lagged prices, and Bushnell (39) applied optimal control to study the effects of Spanish accession to the EC on the U.S. almond industry. No trade models treated the capital stock-nature of supply adjustment in livestock, although work is underway on this topic at the Bureau of Agricultural Economics in Australia.

Of the models surveyed in this section, all were deterministic except that of Sarris, Abbott, and Taylor (215), which was employed for stochastic simulations of alternative reserve stocks schemes. To analyze reserve stocks policies, a stochastic simulator is useful to generate the probability distribution of the relevant variables. In practice, this is generally too expensive to do with multiregion trade models, and most such studies in the literature cast the analysis in a two-region world.

Another limitation of many of the models reviewed in this section is that they are linear. Schmitz and others have argued in (160) that many economic relations, especially stocks demand, are substantially nonlinear. If one uses a linear demand equation, the price elasticity of demand increases as price increases, even though it is widely accepted that the

price elasticity of demand for grains falls as price increases. It is, therefore, likely to be impossible to build a grains market model using linear equations, whose price behavior parallels that of the real world with linear equations. Linear models are, moreover, prone to give nonsensical results, such as negative prices or negative production. Iterative solution techniques for systems of nonlinear equations are readily enough available now that this concern should no longer be a consideration in choosing between a linear or nonlinear specification.

The multiregion nonspatial price equilibrium trade models improve upon two-region models for many purposes because they provide regional supply and disappearance results for the rest of the world. Nevertheless, they calculate only the net trade of each region, and not the market shares or trade flows that are needed for certain purposes. Such models also assume that each commodity is perfectly homogeneous, both in terms of physical characteristics and country of origin. Each importer is assumed to be indifferent as to the supplier country from which it buys the product.

A closely related issue has been raised by Grennes, Johnson and Thursby (91). They analyzed whether the law of one price holds within agricultural commodity aggregates, like "wheat," and found little correlation among prices of the "same" commodity in different countries. They concluded that "Wheat qua wheat is clearly not a homogenous good" (91, p. 12). Only as they narrowed the specification of the product did the correlations increase until the prices of two different countries' export goods became almost perfectly correlated. This shows that even quite narrowly defined agricultural products are in fact aggregates of different goods. On the basis of aggregate data, Grennes, Johnson, and Thursby reject the law of one price. This raises some question about the adequacy of the homogeneity assumption usually made in trade models. This issue is taken up again in the section on market share models, in which this assumption is relaxed.

Two forms of aggregation problems exist in some of the models reviewed--temporal aggregation and regional aggregation. Most of the models reviewed in this section are annual models, yet crops are harvested roughly 6 months out of phase with one another in the Northern and Southern Hemispheres. Two crops of some commodities are harvested each year in both hemispheres. When one builds an annual trade model, one forces events to occur contemporaneously in the model when they do not in fact. This can introduce substantial error into the models' predictions. Frequently, a model's behavior will change quite substantially just by changing the definition of the year. The only solution to this problem would be to go to a 6-month or quarterly specification. However, data and resource constraints often preclude this possibility.

The models reviewed in this section vary greatly in the number and composition of regions included. While generally

determined on an ad hoc basis, the most commonly stated criteria include: geographic contiguity, level of economic development, economic system (centrally planned or market economy), agroclimatic conditions, and nature and level of government policy interventions employed. These appear to be appropriate criteria, but work is needed on defining rules for determining the optimal regional aggregation.

Summary and Implications

Multiple-region, nonspatial price equilibrium models have made several contributions to understanding the interrelations among trading regions. Their most important contribution has been in analyzing the extent to which world market price shocks get transmitted into domestic markets through policy reaction functions or price transmission equations. This has both contributed to knowledge as well as tested trade theory. The multiregion models surveyed here, even where policy variables were inadequately represented, have helped clarify the simultaneities and interactions among trading regions. This has been particularly true in policy analysis models in which the effects of one region's policy change on other regions' supply and utilization are simulated. This is an important way in which this class of models has improved upon the two-region models reviewed previously.

It appears that particularly those models that are specified with one global market-clearing price have worked adequately in forecasting the export price for grains, but there exists very little documentation on the forecasting performance of any model, except that of Kost, Schwartz, and Burris (137). This evaluation, therefore, must remain somewhat tenuous.

Several of the multiproduct models in this class were built for longrun projections. The analyst who makes long-term projections has the advantage that by the time the projections year arrives, most people have forgotten about the projections. It appears that most such models have a built-in bias in the direction of free trade in the long run, but nevertheless consistently underestimate the rate of growth in the volume of agricultural trade.

The empirical content of many models reviewed in this section is suspect--due to a combination of inadequate data and a failure to take adequate account of global simultaneities in the choice of parameter estimation technique. This has severely limited the contribution of these efforts to understanding the structure of the world markets for the commodities studied. It also means that, while many of the policy analyses carried out are indicative of the direction of change in variables, one should not attach much significance to the absolute magnitudes of the effects reported. This is true of own-price terms and even more so of the cross-price terms. Because the sole reason for building multicommodity simultaneous models is to explicitly take into account the cross-price effects among commodities, the whole exercise is rendered doubtful if one can put little faith in the magnitudes of the estimates of the cross-price effects. Improving the empirical content of these models

is the area where future work is most needed at the present time.

For many purposes, multiregion, nonspatial price equilibrium models make an important improvement over two-region models by endogenously determining the supply and disappearance in each of the trading regions in the model. However, these models have the disadvantage that they often link prices together in a manner that is not consistent with spatial price equilibrium. Moreover, the models provide no information on trade flows or market shares, variables of interest to some users. For such purposes, it is common to go to a spatial equilibrium modeling approach, treated next.

SPATIAL PRICE EQUILIBRIUM MODELS

The most common class of agricultural trade models, particularly for comparative statics analysis of the effects of a change in policy, is comprised of the spatial price equilibrium models. The feature that distinguishes these models from the two classes surveyed above is that spatial equilibrium models endogenize trade flows and market shares. The models are structured in a manner consistent with spatial equilibrium theory such that prices are directly linked only between those pairs of countries that actually trade with each other. The data requirements for a spatial price equilibrium model are identical to those for a nonspatial price equilibrium model. Both require internal supply and demand schedules or an export supply or import demand schedule for each trading region, documentation on the levels of all policy variables, exchange rates, and a matrix of transportation costs. The fundamental difference is in solution technique.

Most models of this type have been linear and solved by quadratic programming. The empirical content of many is weak. The disadvantage of linear equations has been overcome by separable programming, Bender's decomposition, and nonlinear solvers. The spatial equilibrium technique, nevertheless, mathematically cannot replicate all the observed trade flows. Reasons why more trade flows occur than predicted by spatial equilibrium theory include: the product may not be perfectly homogeneous, but may be differentiated by country of origin; harvests occur 6 months out of phase in the Northern and Southern Hemispheres; some countries impose quota restrictions on trade flows; and importers may diversify their purchases among several suppliers to spread risk. Nevertheless, work on these models has contributed to carrying out policy analysis and to testing spatial equilibrium theory.

Historical Survey

Most spatial price equilibrium models in the literature have been formulated with linear export supply and import demand schedules for the trading regions and solved using the quadratic programming formulation developed by Takayama and Judge (238, 239). In 1952, Samuelson (212) demonstrated that maximization of the area under all excess demand curves minus the area under all excess supply curves minus total transport costs drives such a model to a competitive (spatial) equilibrium solution. Takayama and Judge's contribution was to show that

this involves maximization of a quadratic objective function subject to a set of linear constraints, that is, it is a standard quadratic programming problem (QP). Bawden (23) and Takayama (235) showed how this general spatial model could be modified to introduce trade policies to make it useful for international trade applications.

The early empirical QP spatial price equilibrium models of world agricultural markets were developed by graduate students of Bawden at the University of Wisconsin in the midsixties, including Schmitz (221) on wheat, Bjarnason (28) and Chung (51) on feedgrains, and McGarry (162) on beef. Two earlier spatial equilibrium trade models were built at the University of California at Davis and solved by an iterative market simulating procedure to approximate a spatial equilibrium solution. These were studies by Dean and Collins (63) and Zusman, Melamed, and Katzer (274) on world orange trade. A number of other applications of the QP technique have followed, including: Shei and Thompson (230) for wheat; Emerson (73), Thompson (251), and Janjaroen (118) for corn; Mack (151) for beef; Martin and Zwart (158) for pork, Bates and Schmitz (19) and Edelman and Gardiner (71) for sugar; Furtan, Nagy and Storey (85) for rapeseed; and Fernandez-Cavada (77) for oranges. Construction of this simple static equilibrium, one-commodity form of spatial price equilibrium model for trade policy analysis has been routinized by development of an input form, matrix generator, and report writer package at Purdue University by Apland, McCarl, Thompson, and Santini (11).

Several modifications of the basic single-priced, static equilibrium QP modeling approach were made in the seventies. Takayama and Liu (240) built a world wheat trade model that not only optimized across space but also simultaneously through time to analyze alternative reserve stocks proposals. In Pieri, Meilke and MacAulay's pork trade model (181), supply was made a function of lagged prices and the model was solved recursively through time. At the University of Illinois, Takayama and several graduate students developed the first multiple-commodity QP agricultural trade model (Takayama and Hashimoto (236, 237)). Hashimoto's multicommodity two-region model (100) reported above was the first phase of this project. Nguyen's (176) thesis developed the eight-commodity, 20-region version of the model. Whitacre's model included nine commodities and five regions (Whitacre and Schmidt (269)). These studies reflect the most advanced state of QP agricultural trade modeling technique to date.

Not all spatial price equilibrium models have been cast in a quadratic programming framework. Moore, Elassar, and Lessley (174) cast the grain and beef trade problem as a classical transportation problem of merely minimizing transport cost, with fixed export and import quantities. Blakeslee, Heady, and Framingham (30) built a linear programming model of world trade in grains, fertilizer, and phosphate rock. The model was constructed to minimize the cost of obtaining and, in the case of fertilizer, expanding, the capacity to produce the commodities

required to satisfy projected "requirements" for grains, nitrogen, phosphate and potash fertilizers, and phosphate rock. In Radhi's (189) model of the world nitrogen fertilizer industry, which included international trade in feedstock, ammonia, and urea, nonlinear fertilizer demand schedules were specified. The model was formulated in the same manner as a QP trade model. It was solved, however, as a separable programming problem, using a linear programming code with grid linearization of the demand schedules, following Duloy and Norton (68).

Two studies specified in a similar manner to the QP trade models were instead solved by reactive programming (King and Ho (132)). These were Jellema's (121) model of trade in peanuts, peanut oil, and peanut meal, and Gemmil's (87) 76-region world sugar trade model.

The area of most recent advances in this class of trade models has been development of the capability for solving nonlinear spatial equilibrium models. Warner (267) has estimated a 33-region nonlinear model of world wheat economy and solved it as a spatial price equilibrium problem by use of a fixed-point algorithm (MacKinnon (152)). Similarly, Holland and Pratt (105) have developed an iterative, nonlinear spatial equilibrium solution algorithm, which is also being applied to world wheat trade.

Evaluation

Quadratic programming has become the most common procedure for solving spatial price equilibrium models of agricultural trade. The procedure is so well established that its use has become routinized, and efficient computer codes for solving QP problems are readily available. One advantage of this approach to solving trade models over those surveyed above is the facility with which policies can be introduced. Tariff barriers are introduced in basically the same manner as in the nonspatial price equilibrium models. However, quantitative restrictions to trade are introduced directly as linear inequality constraints in the constraint set of the QP problem. This is significantly easier than introducing quantitative restrictions with "if" statements in iterative solution techniques for systems of nonlinear equations. So, even if one is not interested in trade flows per se, this flexibility provides one argument for using QP to solve any linear trade model that is not too large.

One severe limitation of the QP formulation is the fact that the export supply and import demand schedules have to be linear. As argued above, there is considerable evidence of nonlinearities in agricultural markets, particularly in the demand for stocks of commodities. One alternative is to use time-varying parameters in the linear equations in the QP formulation. Nevertheless, the separable programming approach taken by Radhi (189), and particularly the new algorithms for solving nonlinear spatial equilibrium problems of Warner (267) and Holland and Pratt (105) provide alternatives to QP with less restrictive assumptions. This appears to be one promising direction for future work to move. Use of the separable programming approach has the advantage that much larger models can

be solved than most QP codes can economically handle. Polito, McCarl and Morin (183) have shown that Benders decomposition can be applied to break large nonlinear models down into a small nonlinear programming model and a large linear programming model. The two can be solved iteratively at a much lower cost than solving the large model by nonlinear programming. They illustrated this with Emerson's world corn trade model (73). Reactive programming (King and Ho (132)) also appears to be an efficient technique for solving larger spatial equilibrium problems than most QP codes can economically handle. This was demonstrated by the ease with which Gemmil (87) solved a 76-region world sugar trade model. A model of this size would have taxed most available QP codes' capacity and would have been much more expensive to solve by that means.

One of the principal arguments for use of the spatial over the non-spatial price equilibrium formulation was that spatial equilibrium models generate trade flows and market shares, variables that are of interest to some users of the models. However, this turns out to be a questionable advantage. Spatial equilibrium models do not explain real world trade flows very adequately. Using 1963-65 trade models, Teigen (246) found correlations between the trade flows in solution and the observed data of 0.89 for rice, 0.79 for coarse grains, and 0.41 for wheat. Any model that explained more than 50 percent of observed trade flows was judged as "adequate," and only the wheat model was rejected on this criterion. It seems, however, that most potential users of such models desire greater reliability than this.

While spatial equilibrium models do generate trade flows in solution, the maximum number permitted in the basic solution is one less than the number of restrictions (rows) in the model. Unless quantitative restrictions (quotas or bilateral agreements) are introduced, there is one row for each exporting country and one row for each importing country. Therefore, in the basic solution of the model, the number of trade flows cannot exceed one less than the total number of exporting (n) plus importing (m) countries (or regions) in the model, i.e., $n + m - 1$, out of a possible $n \cdot m$ flows. In the real world, most exporters ship some quantity each year to each importer, although in practice many of the shipments are quite small. In a perfectly competitive spatial economy, one should expect, in effect, a basic solution to be generated. Any trade flows in excess of this represent departures from the global welfare maximizing spatial allocation of resources, and their existence should lead the analyst to seek alternative explanations for why they should exist.

A number of hypotheses could be advanced to account for these departures, all of which concern invalid assumptions made in the spatial equilibrium formulation. For example, the product may not be perfectly homogeneous. There are many varieties of wheat, each with different principal uses, and they are not perfect substitutes for one another. Moreover, importing countries may differentiate among countries of origin on historical

or political grounds. The crop is harvested out of phase in the Northern and Southern Hemispheres, and some trade flows may be seasonal phenomena.

The spatial equilibrium model assumes perfect certainty, yet the real world is characterized by uncertainty associated with variability in weather conditions and in turn crop yields. In addition, export embargoes may cause importers to view the availability of supply as uncertain and therefore to diversify sources of supply by buying from multiple exporters. Such risk-averse behavior could be reflected in trade models in the same manner as it has been introduced into agricultural sector models, following Hazell and Scandizzo (101). This would permit more trade flows to enter the model solution. There are no known attempts to apply this procedure in trade modeling to date.

There do exist trade policies in the form of quantitative restrictions. Each such restriction added to the model brings one more trade flow into the basic solution. Nevertheless, the fact remains that without a large number of such restrictions, spatial equilibrium models generally do not do very well at accomplishing one of their principal reason for being--to account for trade flows. This casts doubt on the justification for using a spatial equilibrium formulation when trade flows are of particular interest.

One advantage of the spatial equilibrium formulation of an agricultural trade model is that it is an efficient means of examining the effects of changes in transport costs on the net trade positions of the trading regions. Nevertheless, because the trade flows in solution are very sensitive to small changes in transport costs (as well as to policy variables), one must interpret the predicted effects on trade flows with caution.

Such doubts with respect to the spatial price equilibrium approach have raised a number of questions concerning its adequacy for purposes of policy analysis. Nevertheless, the work represents an extensive test of received spatial equilibrium theory and finds that it fails to account well for observed agricultural trade flows. The list of explanations for why spatial equilibrium models may not explain observed trade flows well is really a list of assumptions of spatial equilibrium theory that are not consistent with the reality of agricultural trade. It is in this area that recent agricultural trade research of all kinds has made the greatest contribution to testing theory.

Some users of trade policy analyses need information on the time path of adjustment of supply, disappearance, and price. The modeling work to date has provided little in this direction. Takayama and Liu's dynamic world wheat trade model optimizes simultaneously across regions and through several years by including storage costs as the cost of "moving" wheat from one year to the next. While expensive, due to the large size of the problem, this provided a useful way of studying the

optimum reserve stocks issue. A much cheaper and more manageable approach to making a static spatial equilibrium model dynamic is to express current supply as a function of lagged prices and solve the model recursively through time. The only example of this found in the agricultural trade modeling literature is Pieri, Meilke, and MacAulay's (181) world pork trade model. This is a very straightforward procedure and could make many static, spatial price equilibrium models much more useful for many policy analysis questions.

Another problem with the spatial equilibrium trade models is their assumption that all trading countries behave perfectly competitively. In the world grains market, however, several countries have export marketing boards which exercise a monopoly-like role in export sales. The centrally planned economies and several other countries have import monopolies. The European Community utilizes a variable levy, which, in effect, cartelizes its import firms (Carter and Schmitz (43)). The grain exports of the United States are largely in the hands of four firms. 16/ McCalla (159) has argued the world wheat market behaves like a duopoly; Alaouze, Watson, and Sturgess (8) suggest a triopoly. 17/ This suggests that the perfectly competitive market assumption of the spatial price equilibrium formulation may not adequately approximate the behavior of the market intermediaries who carry on world grain trade.

It is not difficult to alter the objective function of a quadratic programming problem to make every region trade on its marginal import cost or marginal export revenue schedule instead of its export supply or import demand schedule. This, however, inadequately reflects the differences in market structure among trading regions. It would be difficult to build in reaction functions that reflect the changes in either the market behavior or the policy of various regions in response to actions taken by other regions. Market structure is assumed to be competitive, and market behavior is assumed to be fully described by the export supply and import demand schedules, with exogenously given policies (both tariff and nontariff) and transport costs. The latter are taken as given data by the model, which cannot be altered endogenously in the course of solution for a given year. This represents another disadvantage of the spatial relative to the nonspatial equilibrium formulation.

While many shortcomings of the spatial price equilibrium approach have been outlined above, the greatest deficiencies found in most of the studies surveyed were in empirical content. The deficiencies can be categorized in four areas: data deficiencies, specification error, simultaneous equations bias, and validation. Since the data requirements of a spatial price

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16/ See also Sarris and Schmitz (216) on price formation in world agricultural markets.

17/ This literature is reviewed in Paarlberg (179).

equilibrium model are the same as those needed for a nonspatial price equilibrium model, the arguments presented above apply here as well and will not be repeated.

The only additional point to be added here with respect to data is that a matrix of transportation costs is a key input into a spatial price equilibrium model. Reliable data on freight rates are, nevertheless, quite difficult to find. Most studies have taken a cavalier attitude toward the importance of these data and have employed very crude approximations. Many assume a constant freight rate per ton-mile on all routes and base their rates solely on distance between ports. Binkley and Harrer (26) have demonstrated that this assumption is not supported by the data. Other studies have applied an "inflation factor" to a matrix of freight rates used in some previous study. The most commonly cited source is a table of rates for 1964-66 published in Rojko, Urban, and Naive (205, p. 128). The problem here is that rates have not risen at a uniform rate on all trade routes. Harrer and Binkley (98) have recently calculated annual average rates for the principal grain trade routes for 1972-76 based on primary data. These are the most recent conveniently available data on freight rates known.

The second empirical problem with most spatial equilibrium models is specification error. Almost all the models surveyed are partial equilibrium models that treat only one commodity in isolation from all others. Most of the models surveyed contained linear export supply and import demand equations for the respective trading regions. A few models included domestic supply and demand equations and derived exports or imports as a residual. It is most common to specify and estimate the export supply quantity or import demand quantity as a function of only its own price. All other arguments of the domestic supply and demand schedules, including all relevant cross-price effects, are usually omitted. As described previously, Paarlberg and Thompson (180) have demonstrated analytically that even the sign of the effect of a change in trade policy is indeterminate when there is more than one commodity related in supply and demand. The net effect depends on the relative size of the cross-price terms in the supply and demand equations. This means that omission of related commodities from the model can lead to erroneous policy analysis. Specification errors can also bias the estimate of the own price parameter and thereby also contribute to erroneous policy analysis. A related problem concerns the failure to include a domestic stock demand equation in almost all the models surveyed. Without this, a model cannot hope to account for observed price variation. Nevertheless, as described above, a stocks demand schedule that is linear cannot hope to be completely successful at this either for moves very far away from the observed price.

The export supply and import demand schedules in most spatial equilibrium models were estimated by ordinary least squares regression, with quantity a function of only the own price. This procedure is almost certain to produce biased estimates of the price coefficient due to a combination of specification

error and simultaneous equations bias from using OLS. The price coefficients are the key parameters in determining the adjustments in response to any shock, such as a policy change. Therefore, if the estimates of price coefficients are biased, the usefulness of a given model for policy analysis or for any other purpose is highly doubtful. Where the price coefficients or any other parameter estimates in a model are in doubt, sensitivity analysis should be carried out. Such problems with the quality of the empirical content have also limited the contribution that these studies have made to understanding the interrelations among trading countries.

Finally, and closely related to the last point, validation exercises have been neglected in most of the spatial price equilibrium models in the literature. In static equilibrium formulations, some measure of the goodness of fit of the overall model should be calculated, such as the mean absolute deviation or mean squared error of the solution trade flows from the observed base period flows. Alternatively, a Chi-square test could be run between the observed and predicted trade flows for the base year of the model. If the model is specified such that it can be run recursively through time, the same validation tests, such as the Theil-U statistic, should be applied to the model as would be applied to any econometric model. In practice, the only difference between an econometric model of a world commodity market and a spatial equilibrium model of the same market should be the solution procedure; this should not affect the choice of validation criteria. The only thoroughly validated spatial equilibrium model found in the literature was Pieri, Meilke, and MacAulay's (181) Pacific Basin pork market model. After being solved recursively through the time period of the data, three test statistics for model validation through time were reported. A similar procedure would be desirable for all spatial equilibrium models.

Summary and Implications

The spatial price equilibrium formulation has been one of the most popular approaches to agricultural trade modeling, particularly for purposes of policy analysis. This approach has the apparent advantage of providing information on trade flows and of providing an easy means of introducing nontariff barriers, which are particularly prevalent in agricultural trade. As pointed out above, however, this approach does not explain observed trade flows well, and nontariff barriers can be introduced into iterative procedures for solving systems of nonlinear equations. As a result, two of the principal justifications for using this approach are undercut. These limitations are reinforced by the fact that all except the recently developed nonlinear spatial equilibrium algorithms have required linear export supply and import demand schedules. The linearity requirement was a limiting characteristic of QP solvers, although this problem has recently been solved. Future work should seriously consider using a nonlinear solver.

The accumulated spatial equilibrium modeling work has extensively tested spatial equilibrium theory and identified a number of shortcomings. For those reasons, this class of trade

models has probably contributed more in terms of confronting a body of theory with data than any other approach reviewed in this report. But the research to date has fallen far short of its potential contribution to understanding the structure of world commodity markets and the interrelations among the trading regions, due to the weakness in the empirical content of most of the models. Much greater attention should be paid in future work to data problems, correct model specification, choice of an appropriate estimator, and model validation. Where problems are unavoidable, sensitivity analysis should be carried out and reported.

Few of the spatial equilibrium models surveyed here reported as an objective either shortrun forecasting or longrun projections. The spatial equilibrium approach probably has little to contribute here over other approaches.

One of the principal conclusions of this section is that there are few capabilities of spatial price equilibrium models, except for explaining trade flows, and even those are handled at least as well, if not better, by another modeling approach. A number of explanations were presented above for why observed trade flows do not coincide very closely with the predictions of spatial equilibrium theory. One of these was that a "commodity," like wheat, corn, or rice, is not a perfectly homogeneous product and the law of one price does not hold exactly; instead, varietal and quality differences exist. Importers differentiate by country of origin of otherwise physically identical products on historical or political grounds. The class of trade flow and market share models of agricultural trade reviewed in the next section explicitly takes this nonhomogeneity into account in an attempt to account more adequately for variation in observed trade flows.

TRADE FLOW AND MARKET SHARE MODELS

The motivation for developing trade flow and market share models of agricultural trade was the failure of spatial price equilibrium models adequately to account for trade flows and the lack of empirical support for the law of one price in world agricultural markets (that is, the recognition that commodities are not perfectly homogeneous in terms of physical characteristics). Moreover, importers may want to diversify their sources of foreign supply in light of world market uncertainty, and they may differentiate among suppliers of their imports by country of origin on historical or political grounds. In response to these observations, a variety of modeling approaches that focus on explaining the elements of the trade flow matrix have been applied to several agricultural commodities. These include mechanical procedures that transform the trade flow matrices from one year to the next without regard for price, econometric models designed to explain one or more elements of the trade flow matrix, and a modification of the spatial equilibrium model in which the elasticity of substitution among sources of supply is less than infinite in each importing region.

The mechanical techniques generally lacked normative content and can offer little guidance for policy formulation, although

they may be useful for forecasting. A number of attempts have been made to estimate demand equations for exports by destination, market share equations, and elasticities of substitution for various agricultural commodities. These generally support the hypothesis that goods are differentiated by country of origin. In the few attempts to integrate this finding into complete agricultural trade models, however, the empirical content was weak. This is an active current area of research.

Historical Survey

There are two basic categories of trade flow or market share models that have been employed to explain or predict agricultural trade flows more adequately than the spatial equilibrium models. The first is a group of relatively mechanical techniques used to decompose past changes in the observed trade flows. This category is characterized by the lack of a role for prices in the decomposition process. The second category comprises models with explicit economic content and which implicitly or explicitly assume that U.S. exports of a given commodity are not perfect substitutes for exports from other countries in each importing country. This category includes econometric models in which an equation is estimated to explain the variation in each element of the trade flow matrix, as well as full trade models in which the elasticity of substitution among alternative sources of supply to each importing region is a parameter that affects the solution. This includes the so-called Armington approach to trade modeling. The studies in each category are reviewed in turn.

Abel and Waugh (3) arrayed world wheat trade flow data in a zero-axial skew symmetric matrix and derived "transition matrices" which, when multiplied by one year's trade flow matrix, would transform it into the next year's matrix. They utilized the elements of the transition matrices to measure historical trends and variations in trade flows.

A technique used more widely to analyze historical trade flow data is the constant market share approach. 18/ This approach assumes that each exporter's market share in each import market will remain unchanged through time unless something happens to alter that exporter's "competitiveness." The technique proceeds to decompose a given country's export growth into fractions attributable to the overall growth in world exports, the differential growth rates of the various import markets, the structure of preferential trading arrangements, and "competitiveness," which is measured as a residual. This approach has been applied to analyze Canadian wheat exports by Rigaux (203), Australian wheat exports by Sprott (233), U.S. fresh and preserved fruit exports by Dunmore (69), U.S. grain exports by Hurtado (114, Ch. 4), and world soybean trade by Uehara (261).

A related approach to studying trade flows is through probabilistic trade models, following Savage and Deutsch (217).

18/ See Leamer and Stern (146, Ch. 7) and Richardson (199) for reviews of applications in nonagricultural trade.

Assuming origin-destination independence, this approach calculates the probability of any particular shipment originating in country i and terminating in country j as the product of country i's global export share times country j's global import share. The expected trade flow from country i to country j, then, equals this probability times the total volume of world trade. Following Savage and Deutsch, Carney (42) calculated an index of "trading intensity" as the ratio of the observed to the expected volume along each origin-destination trade flow. He argued that any divergences of observed from expected flows reflect geography, taste, comparative advantage, or discriminatory trade policies. Trading intensity indices were calculated for European-U.S. agricultural trade. Schmidt and Vandenborre (220) employed a similar framework for evaluating preference patterns in world coarse grain trade. Konandreas and Hurtado (134) integrated this approach with the constant market share approach to evaluate the relative performance of the major grain-exporting countries over the period 1950-74.

Recognizing that importing countries view imports of the same product from different exporting countries as imperfect substitutes, despite the fact that their prices move closely together, Markov models have also been applied to predict market shares. This technique follows Telser's (248) approach to analyzing domestic demand for branded goods and does bring prices into the explanation. Telser developed a probabilistic theory of demand in which consumers will tend to switch purchases from brands whose prices have risen to brands whose prices have fallen. However, even under unchanging relative prices, consumers may still switch their purchases among brands as part of an ongoing search for brands most suited to their tastes. Telser's model postulates the existence of transitional probabilities that are functions of the relative prices among all brands. These transform the matrix of market shares of one period into that of the next. Price elasticities of market shares are derived from the transition probabilities as well. This approach has been applied to international wool trade by Dent (67) and to the U.S. market share in the European Community import demand for grains by Hurtado (114, Ch. 5). This approach provides the transition to trade flow models with more economic content.

The second subclass of models surveyed in this section implicitly or explicitly assumes that U.S. exports of the commodities of interest are not perfect substitutes for exports from

other countries in each importing country. 19/ A common application has been to estimate equations that explain the shipments from a given exporter to each foreign destination. These are usually represented as regional import demand equations for the given country's exports. Examples include: Houck, Ryan, and Subotnik (112) for U.S. soybeans and products, Capel and Rigaux (41) for Canadian wheat, Konandreas, Bushnell, and Green (136) and Fletcher, Just, and Schmitz (81) for U.S. wheat. Ward (266) estimated a European demand function for Florida frozen concentrated orange juice, and Lattimore (143) estimated a Soviet demand schedule for U.S. feedgrains. Taplin (242) estimated separate rest-of- the-world import demand equations for hard and soft wheat from the five principal exporting countries.

Another approach has been to estimate a total import demand equation for each importing region and separate market share equations for the United States and other exporters. This procedure has been employed by Tsujii (257) for the world rice market, Mitchell (170) for wheat, feedgrains, and soybeans from the United states, Fisher (79) for wheat from Australia, and Bedestenci (24) for soybeans and soybeans products from the United States.

The assumption that importers differentiate among goods by country of origin, regardless of any qualitative differences, implies that the elasticity of substitution between countries of origin is less than infinite. Support for this hypothesis has been found in several studies, including Capel (40) on flue-cured tobacco, Reekie (195) and Capel and Rigaux (41) on

19/ The second subclass includes models known as structure of trade models. These involve specifying and estimating econometric equations to explain the individual elements of the trade flow matrix. This approach was first developed to analyze aggregate trade flows among countries by Tinbergen (254, app. 6) and Linnemann (148) in the Netherlands and by Poyhonen (184) and Pulliainen (186) in Finland. After compiling trade flow matrices, they specified each element as a function of export-supply factors in the exporting country, such as its resource endowment, import-demand factors in the importing country, such as its domestic demand structure, and the "resistance" to trade between the pair of countries. The "resistance" to trade included such factors as distance (or transport cost), tariffs, membership in the same political bloc, sharing a common border, speaking the same language, ownership patterns of multinational firms engaged in trade, and product differentiation. Such equations are also known as "gravity equations," particularly in location theory and economic geography, although the economic content is often minimal in their specifications. The technique has been implemented by Tilton and Dorr (253) for international trade in various minerals. All other known applications have been for aggregate trade or trade in manufactured goods.

wheat, Sirhan and Johnson (231) on cotton, 20/ Collins (58) on coarse grains, and Hurtado (114, ch. 6 and 7) on grains in the European Common Market.

Armington (13) has developed the theory for a class of trade models in which goods are differentiated by country of origin. This approach assumes that utility is weakly separable so that the consumers' decision process may be viewed as occurring in two stages. The total quantity of a commodity to be imported is first determined, and then this quantity is allocated among the competing suppliers. To simplify the model and reduce the number of parameters to be estimated, it further assumes that the total quantity of the product imported is a constant elasticity of substitution (CES) index of the quantities imported from the countries of origin. Given these assumptions, the cross-price elasticities between all pairs of countries of origin can be calculated from estimates of only the overall price elasticity of import demand and the (assumed constant) import elasticity of substitution and data on import shares. The cross elasticities, therefore, need not be directly estimated.

Most applications of this technique to agricultural commodity trade have been carried out at North Carolina State University, where most of the work on estimating elasticities of substitution has been done. It has been applied there by Grennes, Johnson, and Thursby (92) to world wheat and feed grains trade and by Collins (58) to world feed grains trade. (See also Johnson, Grennes, and Thursby (127).) It is currently being applied by Sarris at the University of California, Berkeley, to fruit and vegetable trade.

Resnick and Truman (196) relaxed several of Armington's restrictive assumptions, in particular that the elasticities of substitution need be constant and identical for every market and between all pairs of suppliers to each market. To do this, they specified a multistage decision process in place of Armington's two-stage process. Total imports are determined first and then imports from a sequence of successively smaller geographic regions are determined in turn. This approach has been applied by Wells and Johnson (268) in a study of United Kingdom wheat imports.

Evaluation 21/

A principal objective of most studies surveyed in this section was either forecasting or improving our understanding of past changes in agricultural trade flows. In addition, some studies sought to contribute to knowledge of the price responsiveness of import demand and, in turn, to improve upon existing models for policy analysis.

20/ The studies by Capel (40), Reekie (195), and Sirhan and Johnson (231) are summarized in Johnson (124).

21/ Leamer and Stern (146), Sarris (214), and Hurtado (114) were helpful in preparing this evaluation, as were detailed comments by Magiera on an earlier draft.

The first set of studies reviewed involved application of purely mechanical manipulations of trade flow data. While such approaches can provide insights into historical developments, this type of analysis has no normative content and can provide no guidance for policy formulation. Nevertheless, these models generally reproduce observed trade flows more faithfully than do spatial equilibrium models.

The objective of constant market share analyses has been to understand past growth in exports and changes in trade flows and market shares. It is doubtful, however, whether this approach can provide any useful information. The approach merely applies an identity to disaggregate past changes in trade flows and totally ignores supply and demand forces in the exporting and importing countries, as well as in all other countries. It also ignores the impact of trade policies and domestic policies on trade flows. In addition, the term "competitiveness" as used in the constant market share models is very misleading.

The results are sensitive to the choice of base period (a standard index number problem), as well as to what region is chosen as the basis for comparison. Being a deterministic approach, it is not possible to make probability statements concerning the reliability of the conclusions reached. The most damaging criticism, however, has been raised by Richardson (201), who demonstrated that the relative magnitudes of the respective "effects" calculated in this approach are sensitive to the sequence in which they are calculated. The lack of theoretical foundations and the problems with the methodology suggest that the constant market shares approach to studying agricultural trade flows has little to recommend it. The same criticisms apply to the probabilistic trade models.

The Markov approach is the only one of the mechanical approaches to analyzing trade flows that has explicit theoretical foundations, being based on Telser's (248) approach to analyzing demand for branded goods. While its performance to date in accounting for observed trade flows can be judged as only partially successful, this, nevertheless, appears to be the only one of the mechanical approaches that has predictive power and may be useful for forecasting. To date, this method has performed least well in accounting for trade flows that are dominated by concessional sales. Hurtado's application assumed that the c.i.f. prices from all origins were the same in each importing country, so the market shares were not specified as a function of relative prices. While it would be computationally difficult, building in relative prices ought to add to the explanatory power of the model. In addition, the explanatory power of the model might be increased by regressing the deviations of the predicted from the observed trade flows on several "resistance" variables (148, p. 183). While the Markov approach has been little employed to date in agricultural trade studies, further applications and extensions of the method appear to be worthwhile.

The second category of models reviewed in this section included econometric equations, which seek to explain individual elements of the trade flow matrix. 22/ There are also several problems with this empirical approach. While the equations are often specified in log-linear form, some trade flows for individual commodities are zero, and the logarithm of zero is undefined. This suggests that an alternative functional form is called for, and linear equations are most often chosen. Most linear specifications produce internally inconsistent results in that the total shipment to or from a given country does not equal the sum of the individual trade flows. The estimated equations may also predict negative trade flows. The adding-up problem appears to be more of a problem for prediction than when the approach is used to decompose historical trade patterns. Hickman and Lau (103) have devised a linear trade shares model that takes explicit account of the adding-up properties of trade flows on both the import and export sides and, by using a constrained estimation technique, guarantees that world exports equal world imports in the system. Their specification is an approximation of Armington's formulation. Although there is no published application of this procedure to agricultural trade flows to date, it is being applied by Magiera at USDA to EC trade in fresh oranges.

The most common use of econometric trade flow equations has been to explain the shipments from one country to all foreign destinations. This has been used for policy analysis models in which the impact of a proposed change on the market share in each export market is needed by decisionmakers. The equations estimated are usually represented as "regional export demand equations." Many of these suffer from the same specification and estimation problems as the export demand equations in two-region models discussed previously. Those arguments will not be repeated here. Ryan (211) has argued that estimation of such regional demand equations for U.S. exports is justified only if the exporting region holds a constant marginal share of each region's imports of the commodity through time. With the volatile world commodity markets of the seventies, it is unlikely that empirical support for this condition can be found. Most studies in this category failed to recognize that they were implicitly assuming commodities to be differentiated by country of origin. They fall in the same class as equations specified to estimate the elasticities of substitution.

Several attempts have been made to test the hypothesis that commodities are differentiated by country of origin in the eyes of the importer by estimating the elasticities of substitution between pairs of exporters in various import markets. The empirical results to date provide some support for this

22/ The theoretical foundation for many "structure of trade" specifications is weak. J. Anderson (9), however, has recently provided a theoretical basis for the gravity equation, but only under very restrictive assumptions, including identical homothetic preferences in all countries.

hypothesis, even though these studies have had problems. First, it is very difficult to estimate an elasticity of substitution between pairs of exporters of agricultural commodities because the c.i.f. price series tend to be highly collinear. Moreover, it is often difficult to obtain data series on c.i.f. prices by country of origin. One means of overcoming certain data problems has been to pool cross section and time series data (Johnson (124)). This has the disadvantage of forcing the same elasticity of substitution between all pairs of exporting countries.

There are several more fundamental problems with the way the elasticity of substitution is usually estimated. The estimation equation is usually specified with the logarithm of the ratio of the quantities of the product imported from two origins as a linear function of the logarithm of the relative c.i.f. prices from the two origins in the importing country. 23/ Leamer and Stern (146, p. 62) have shown, to obtain this functional form, some severe constraints have to be put on the parameters of the domestic supply and demand schedules. These are: (1) The algebraic sum of the own- and cross-price elasticities of demand for the commodity from the two origins must be equal, and (2) The income and other price elasticities of demand for the two must be equal. In other words, the commodity from two different origins must be alike in all economic respects except that they are not perfect substitutes. Richardson (198) tested these assumptions on two disaggregated classes of manufactured goods and found substantial empirical evidence that they hold.

Johnson (124) has also identified an econometric problem with estimating the elasticity of substitution by this means. He argues that there is no reason to assume that the error term is associated only with the quantity ratio since prices and quantities are simultaneously determined. If there are errors in both the quantity and the price ratios, the OLS estimate of the elasticity of substitution will be biased toward zero. It appears that most users of this approach have not worried about this problem or whether the necessary theoretical assumptions have been satisfied in practice. Also, some of the empirical

23/ Hurtado (114, pp. 156-161) has demonstrated that c.i.f. prices are clearly preferable to f.o.b. prices, although some researchers, e.g., Capel and Rigaux (41), have employed f.o.b. prices or f.o.b. unit values. Scobie and Johnson (226) have demonstrated that when one lacks price series but has value and quantity data, the elasticity of substitution can be bracketed by regressing value ratios on quantity ratios and vice versa. They show that if values are divided by quantities to generate a price series and both regressions run, both estimates will be biased toward zero. Tryphos (256) has argued that, given the nature of available data and conditions typically prevailing in international trade, estimates of elasticities, "are not only unreliable but are often biased and may be potentially dangerous as a basis for policy decisions."

results have been weak due to data problems, in particular the high degree of collinearity between the price series. Nevertheless, the relatively small number of agricultural trade studies of this type provide sufficient empirical support for the differentiation by country of origin hypothesis that it cannot be ignored. More work is needed with better data to test the hypothesis under a broader range of conditions to determine the extent to which it does hold. In addition to testing theory, these studies have contributed to understanding how world agricultural trade works.

The Armington approach to trade modeling, by explicitly introducing elasticities of substitution, can generate trade flows between all pairs of trading countries in solution. This represents a significant generalization of the spatial equilibrium model. (The spatial equilibrium model is a special case when all elasticities of substitution are infinite.) The model gives much smoother changes in trade flows in response to shocks than does the spatial equilibrium approach. The approach, nevertheless, does have several drawbacks. In particular, the utility function assumed implies the same (constant) elasticity of substitution between all pairs of exporters in all import markets. There seems to be a logical inconsistency between assuming a commodity is differentiated by country of origin and then assuming the same parameters. This assumption is unduly restrictive, 24/ and has been relaxed by Resnick and Truman (196). In addition, Artus and Rhomberg (14) have generalized the Armington model by replacing the CES index functions with constant ratios of elasticities of substitution and homothetic (CRESH) index functions. This increases the flexibility of the model at the cost of greater computational complexity.

The Grennes, Johnson, and Thursby (92) study was the first to apply the Armington approach to trade in agricultural commodities. While the objective of their study was to predict trade flows, they also carried out policy analysis with their model (90, 126). Rather than directly estimating the elasticities of substitution among countries of origin for the commodities of interest, they assumed an elasticity of -3 among all pairs of suppliers in all markets on the basis of the existing estimates for several agricultural products reviewed above. Unfortunately, the model was not well validated, and, as Sarris (214) showed, their models do not predict trade shares as well as the

24/ It is important to note why Armington made this assumption. He states that even under the assumptions of want-independence and a linearly homogeneous utility function, the resulting demand equations would probably be too complicated to be of practical use if many countries or areas were identified in the model (13). In other words, these latter assumptions would not be necessary were there only a few exporters in the model. These assumptions are also helpful when insufficient time series data are available. While the Armington system may be very restrictive, it was a start at practical, full-system trade flow modeling.

naive constant market share model. This one example, however, does not provide sufficient evidence to condemn the Armington approach. More evidence on the magnitudes of the elasticities of substitution and more work on tuning and validating the existing models are called for before deciding how widely to use this approach. Collins (58), after applying the Armington approach to coarse grains trade, concluded that the constant elasticity of substitution assumption was too restrictive and recommended a less restrictive index function than CES. This was done on a limited scale in Wells and Johnson's (268) application of the Resnick and Truman (196) approach.

Summary and Implications

Development and applications of trade flow and market share models have been the frontier of agricultural trade modeling technique for the past decade. As a result, many of the approaches surveyed here are still very much in a state of flux. Many of the approaches seem to account for the observed variation in trade flows more adequately than do spatial equilibrium models. Nevertheless, the theoretical foundations for several of the approaches are either nonexistent or of doubtful validity. As a result, their usefulness for prediction and for policy prescriptive purposes is severely limited. Few of the models include much policy or institutional content, two factors that may help account for that part of observed behavior that these models have failed to explain. Finally, as in all the other classes of agricultural trade models surveyed here, the empirical content of many of the studies reviewed leaves much to be desired, due to deficient data, specification error, or choice of an inappropriate estimator. As a result, their contribution has not been as great as their potential.

The principal contribution to date in this area has probably been in testing theory. The conventional assumption of product homogeneity has been tested and found wanting. Support has been found for the hypothesis that importers differentiate among commodities by country of origin. This work has also contributed to understanding how world commodity trade works, although not as much as it could have if more care had been taken with the empirical content of the models that were built.

It appears that techniques like the Armington approach and its extensions offer considerable potential for improving trade flow forecasting and for policy analysis. However, this potential has not been realized to date, due in part to weak empirical content and to the few times that empirical application of the approach was attempted. Much more work is needed both on extending the modeling technique under less restrictive assumptions and on improving the empirical estimates of the relevant parameters.

APPRAISAL AND RESEARCH NEEDS

The accomplishments of the last decade's work on agricultural trade modeling and forecasting are evaluated in this section relative to the objectives of such efforts. This is followed by general observations on agricultural trade modeling. Those objectives are, to recapitulate: (1) to contribute to

knowledge of the interrelationships among trading countries, (2) to test trade theory, and (3) to provide forecasts, policy analyses, and projections for policymakers and other decision-makers. The variables of particular interest are the U.S. export volume, the market price, supply and utilization in one or more foreign regions, and the U.S. market share by export destination.

Recent agricultural trade modeling has fallen short of its potential for contributing to understanding of the world market and the interrelationships among countries through trade. Most studies paid much more attention to the mathematical structure of the model than to the quality of the empirical content. There is much more professional recognition for the researcher who applies a sophisticated new technique than for one who carefully estimates supply and demand schedules, regardless of whether the numbers that come out of the sophisticated model bear any resemblance to reality. Almost none of the models surveyed above reported validation statistics on the models' tracking ability through time, and few reported base year validation statistics. Sensitivity analysis was rarely performed. In general, little concern was expressed concerning whether the constraints forced upon the data by the solution technique are consistent with reality. Put another way, each solution technique embodies a theoretical model of how the world market works, and in some cases, the theory may be wrong.

The data requirements for building a world trade model in even one commodity are very large. There is no one publication or data bank where all the necessary data on other countries can be conveniently found. While FAO and USDA sources are very helpful for quantity data on grains, no organization publishes internal market prices and policies or quantity data on other commodities on a comparable basis for most countries of the world. Therefore, the researcher, with no alternative but to collect the data from disparate national sources, may sometimes use data of questionable quality and with only a weak correspondence to the theoretical concept the analyst set out to measure. Until USDA, FAO, or some other organization begins to maintain such a data bank, there will be no alternative to the tedious, time-consuming, and often expensive data collection and evaluation process, if the empirical content of the existing agricultural trade models is to be improved.

There is one source of information, seldom tapped to date, that could help improve the empirical content. That is the growing number of national agricultural sector models built for many countries. These models could provide much better information than is usually included in trade models on the structure of supply and demand in the countries for which such models are available. In this sense, the International Institute for Applied Systems Analysis world agricultural modeling exercise has great appeal.

Nevertheless, even in those cases where adequate data were available, specification error and the choice of an

inappropriate estimator resulted in biased parameter estimates in many of the studies surveyed. This is a second common cause of the failure of trade models to contribute as much to understanding the world market as they could. There is little excuse for such errors because computer packages for various limited and full information estimators are widely available. The contribution of agricultural trade modeling to understanding the world market in the future can be substantially increased by researchers' being more careful about data collection, by their using correct specifications of the relations to be estimated, and by their using an appropriate estimator.

The second objective of agricultural trade modeling is to test theory by confronting it with data. The most important accomplishment in this area has been in testing spatial equilibrium theory in the trade context and finding that it does not predict trade flows well. The "law of one price" has also been tested, although less extensively, and the data provide, at most, weak support for it at the level of commodity aggregation at which most models are specified. These empirical findings led to development of a hypothesis that products are differentiated by country of origin in the eyes of each importing country. While subject to some methodological limitations, the attempts at estimating elasticities of substitution support this hypothesis. The Armington trade model, which was built around this hypothesis, does account more adequately for trade flows than the spatial equilibrium model. This work has contributed not only to testing a body of theory, but also to understanding how world trade works.

The multicommodity trade models have generally not included enough empirical content to test the received theory on the commodity composition of trade, except for Valentini and Schuh's (264). Similarly, the theory of commercial policy has been little tested, except in Carter and Schmitz's (43) study of the extent to which the EC and Japan are imposing the optimum tariff on grains. Anderson (10) specified a theoretical model of the supply and demand for protection to explain the varying levels in the different sectors of open economy, but that model has been little tested, except in his application in Australia. The efforts at estimating government policy reaction functions could easily be extended to test this theoretical framework. In past work, the specification has generally been more ad hoc than guided by a body of theory, like Anderson's model. In addition, a growing body of qualitative studies argues that the world market conforms weakly to that of perfect competition, the system being dominated, instead, by large trading countries and companies and by state traders (160). Nevertheless, indicators of structure, conduct, and performance are purely descriptive and do not test theory. It is now necessary to formulate testable hypotheses concerning behavior of both state traders and large market intermediaries in the world market to test whether or not the market functions as if it were perfectly competitive. The closest one comes to this in the literature is Carter and Schmitz's optimum tariff "test." If the empirical evidence does not support the

competitive behavior hypothesis, this has very important implications for how world trade models should be structured.

All studies reviewed in this report assume that markets clear and that prices reach equilibrium. Nevertheless, recent econometric work on domestic economies has begun to question whether all markets reach equilibrium. For example, Chambers and others (47) argue that it is more appropriate to study the international beef market with a disequilibrium model. More work along this line is needed to investigate under what conditions it is more appropriate to specify a disequilibrium trade model. By testing received theory in this manner, trade models help theory to advance. It is important to test the theory that underlies a model because no model can help one to understand the real world if the theory on which it is based is not consistent with reality.

The third objective of building agricultural trade models is to provide a basis for improved forecasting, policy analysis, and projections for decisionmaking. Of those three, forecasting has received the least quantitative research. More studies list policy analysis as the objective than any other.

Little, if any, contribution seems to have been made by agricultural trade modeling to shortrun forecasting. Most trade models are annual models and therefore say nothing about periods of less than a year. This is in part due to the fact that most trade statistics are published annually. Where quarterly trade data are available, use of well specified reduced forms or applications of time-series techniques, such as Box-Jenkins, could provide the basis for improved forecasting. In practice, most trade forecasting is now done by commodity market experts--on the basis of judgment and knowledge of the markets, not models. Combining expert opinion with model forecasts in the form of composite forecasts could potentially produce better forecasts than either in isolation.

One important obstacle to shortrun trade forecasting is the extent to which shortrun world market developments are dominated by changes in weather conditions throughout the world. Until the meteorologists improve their long-range weather forecasting ability and the agronomists improve their yield prediction equations, short-term trade forecasting will continue to be hampered, leaving expert opinion to dominate the models' forecasts.

Of the few modeling exercises that did list forecasting as an objective, almost none provided any forecasting performance measures out of the range of the data used to estimate the model. To gain credibility, it will be essential for the forecasting properties of models to be documented and published. More work is needed to improve our trade-forecasting capability, however, due to the volatility of exports and the very limited shortrun data availability, it is not anticipated that this will be an area of rapid progress in the near future.

Agricultural trade models more often list policy analysis as their objective than any other. Most have been designed to analyze what would happen if some policy were changed, not to design optimal policy (except in the case of reserve stocks of grain). Most analysis has been static, focusing either on the shortrun impact or the longrun full equilibrium adjustment to the policy change. Few have treated either the time path of adjustment or the distributional effects of the policy change. Most analysis has been partial equilibrium, focusing on one commodity at a time without regard for other interrelated commodities even though the cross-price effects can offset part of the measured effects. Most studies assume all other policies in all other countries remain unchanged in response to the policy change being studied. They ignore the possibility that other governments may react to offset part of the estimated effect. Each of these features can range from a mild to a severe limitation of the studies, depending on the circumstances. In general, the techniques of agricultural trade policy analysis have been advanced significantly in those recent studies that have attempted to endogenize policy interventions.

The most common deficiency found in the studies was their generally weak empirical content. As a result, one can rarely place much confidence in the magnitudes of the changes predicted by the models. If the numbers that come out of a model are not correct, they may lead to wrong policy decisions. Nothing can destroy the credibility of quantitative models faster than this as a useful input into policymaking. Much work is needed on improving the empirical content of the already existing agricultural trade models.

Several of the agricultural trade models surveyed were built for longrun projections. Such models have tended to underestimate the rate of expansion in the volume of agricultural trade although no ex post facto evaluation of the projection performance of such models has been carried out. Nevertheless, it is essential to keep in mind the objective of making long-term projections, namely, identifying what will likely happen if present trends continue. The reason for doing that is to identify potential problems such that policy changes can be implemented in time to avoid undesirable consequences. Projections models, for that reason, cannot be condemned if they fail to forecast actual events well. Nevertheless, for many purposes projections models tend to be too rigid. If they include any policy variables at all, the policies are usually fixed rigidly throughout the projections period. Some models use systems of linear equations, which, when shifted through time at differing rates, can produce implausible results. Technological change is usually projected only as a linear trend without regard for changing input market conditions. Demand elasticities are usually assumed to be unchanging as per capita income grows. As in the other types of models, the empirical content of the projections models also leaves much to be desired. These are areas in which further research could improve the projections capability.

To sum up, the contribution of recent agricultural trade modeling work to improved decisionmaking has fallen short of its potential. This has been principally a result of inadequate attention to the quality of the parameter estimates and to the validation and fine tuning of the models prior to proceeding with the forecasting, policy analysis, or projections. Underperformance in some cases, has been due to inappropriate theoretical frameworks and associated solution procedures. In this regard, it is important to bear in mind that the data and estimational requirements are almost identical for most of the different approaches to multiregion trade modeling that were reviewed. The main differences among the procedures are in the mathematical structure of the model and the constraints consequently imposed on the model's behavior. The distinction to be made here is not between econometrics as opposed to other modeling approaches. Rather, econometric techniques are first required to estimate the parameters for all the modeling approaches. Then one must select the technique for solving the system of equations that conforms most closely with the theoretical framework judged to be most appropriate for the given problem. It is essential for the trade modeling team not only to know quantitative methods, but also to have a solid grounding in economic theory and a thorough acquaintance with the real world phenomenon being studied.

Before concluding, the issue of the optimal size or level of detail of a trade model merits discussion. Because of the global nature of the issues and the complex interrelationships both among countries and among commodities, it is easy for a trade model to grow very large. The world is general equilibrium in nature, and ultimately everything does depend on everything else. Nevertheless, in empirical research the analyst has to impose separability at some point, after which the prices in all other sectors are assumed exogenous. In practice, the "correct" point at which to do this is difficult to determine. The researcher must ultimately rely upon his or her judgment as to when the exclusion of a given sector or variable from a model will not appreciably affect the results for the sector(s) of interest. The test to apply at every turn is, "Does it matter? Will one learn enough more from the model by including additional detail to compensate for the additional cost in data acquisition, estimation, and model complexity?" Very large models tend to be cumbersome to use and to keep up to date. Solution cost and turnaround time tend to increase at a faster rate than the size of the model. Models can easily become so complex that one cannot distinguish between a programming error and an unanticipated general equilibrium effect. Validation and fine tuning often become virtually impossible when a model becomes too large. There is no necessary direct relationship between the dimensions of a model and the understanding it can provide of the real world. Small models can be very sophisticated.

The "ideal" multicommodity, multiregional trade model is probably an unattainable target. No one model can satisfy all objectives of all users. While it is desirable to maximize the

flexibility of any trade model in order to spread the development cost over as many uses as possible, the extent to which this is possible is limited. There is great appeal in maintaining a linked family of regional models, various components of which can be combined at different levels of aggregation to respond to different questions when they arise.

The last decade witnessed considerable progress in attaining several of the objectives of agricultural trade modeling. The two principal challenges now are to strengthen the empirical content of the existing models and to modify the presently available solution techniques to make them more consistent with observed structure and behavior in world commodity markets. This will not be an easy task, but world agricultural trade has become too important to the United States for the profession not to get on with it.

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